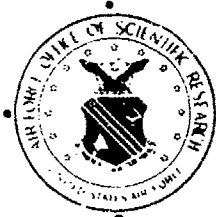ITIC FILE COPY

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This is a quarterly publication presenting articles covering recent developments in Far Eastern (particularly Japanese) scientific research. It is hoped that these reports (which do not constitute part of the scientific literature) will prove to be of value to scientists by providing items of interest well in advance of the usual scientific publications. The articles are written primarily by members of the staff of ONR Far East, the Air Force Office of Scientific Research, and the Army Research Office, with certain reports also being contributed by visiting stateside scientists. Occasionally, a regional scientist will be invited to submit an article covering his own work, considered to be of special interest. This publication is approved for official dissemination of technical and scientific information of interest to the Defense research community and the scientific community at large.

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18. Subject Terms (continued)

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Computer systems
Knowledge information processing system
Magnetic shielding
Shielding by a spherical shell
Neuroendocrine modulation
Bidirectional communication between brain and immune system

Ceramic superlattices
Calcium ionophores
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Powder metallurgy
Titanium sponge
Fifth generation computer system
Sequential logic programming language
Magnetic shaking
Immunopharmacology
Muramyl dipeptide in the brain
Neuroleukin
Cytokine research

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> *Japan's FGCS is an advanced information processing computer with an intelligent inference capability designed to address the expected social and economic problems of the 1990s.*

> *Metglas 2705M, an amorphous soft magnet with small magnetostriction and highly rectangular hysteresis loop, can be used to increase shielding.*

> *An interesting trend towards attempting pharmacological manipulation of the immune system via neuroendocrine modulation surfaced at this conference.*

Cover: Yasunari Kawabata, Japan's Nobel laureate for literature in 1968, wrote his first novel about a student and a young dancing girl. Below the Amagi Pass in Izu, where the scene was set, stands this charming commemorative statue of the two young people. Photograph courtesy of Solveig G. Wright.

DIMENSIONAL CROSSOVER IN SUPERCONDUCTING SUPERLATTICES

Ivan K. Schuller*, Masashi Tachiki, and Earl Callen

With modern thin film vapor deposition techniques it is possible to construct superlattices of high compositional integrity, with little diffusion between layers. Layer thickness can be exactly controlled. Superlattices have been made with superconductors intersheaved with insulators, with semiconductors, with normal metals, with ferromagnets, and with other superconductors. At Yamada Conference XVIII on Superconductivity in Highly Correlated Fermion Systems, Sendai, Japan, 1987, one of us reviewed the properties of such superlattices. This article treats dimensional crossover in superconducting superlattices. Dimensional crossover describes a transition of the upper critical field parallel to the superlattice from the linear temperature dependence characteristic of three-dimensional bulk material to the square root dependence of thin two-dimensional films as the temperature is reduced. The cause of dimensional crossover is the contraction of the perpendicular coherence length to a size less than the nonsuperconducting layer thickness and a consequent uncoupling from each other of the superconducting layers in the superlattice.

INTRODUCTION

At Yamada Conference XVIII, Sendai, one of us discussed the superconducting properties of superlattices (Ref 1). For review articles see References 2 and 3. Thin films; sandwiches of superconductors with other superconductors, with normal metals, and with insulators; and multilayered and superlattice structures all have properties different from bulk, single-component materials.

The upper critical field H_{c2} of a bulk, isotropic superconductor is inversely proportional to the square of the coherence length. This produces a characteristic linear temperature dependence. In thin films there are two upper critical fields, H_{c2perp} and H_{c2par}.** When the field is perpendicular to the surface, persistent currents circulate in the film plane much as in the bulk, and H_{c2perp} is not greatly affected. But when the field is parallel to the surface, and when the coherence length ξ is greater than the film thickness d, H_{c2par} depends inversely as d ʳ rather than ξ^2. In superconducting superlattices, likewise, H_{c2perp} is as in bulk, single-component materials, but H_{c2par} has

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** Because of software limitations on typography in subscripts and superscripts we must use unconventional notation:

$$H_{c2perp} = H_{c2\perp} \text{ and } H_{c2par} = H_{c2\|}$$

$$\xi_{perp} = \xi_{\perp} \text{ and } \xi_{par} = \xi_{\|}$$

new features. In superlattices fabricated with thin insulating layers or with semiconductors, superconducting electron pairs, Cooper pairs, can tunnel through the intermediate layers. Josephson-coupled superlattices behave like bulk, single-component materials when the coherence length is large but like stacks of thin films when the coherence length is small compared to the layer thickness. Since coherence length changes with temperature, so does the temperature dependence of the upper critical field. Superlattices in which the alternate layers are normal metals are coupled not by Josephson tunneling but by the proximity effect; individual electrons travel between the superconducting layers. The result is once again that there are two temperature regimes of H_{c2per}. The theory of proximity-coupled superlattices has only recently been worked out.

BACKGROUND

Research on the properties of films was pioneered by Meissner (the Younger) (Ref 4), soon followed by Smith et al. (Ref 5), Rose-Innes and Serin (Ref 6), Simmons and Douglass (Ref 7), and by Hilsch (Ref 8). The early workers had to cope with interlayer diffusion, contamination, uneven film thickness, and voids. With the advent of sophisticated thin film vapor deposition techniques it became possible to create layered structures of a very high degree of geometric regularity. Consequently the theory now has firm data to explain.

Not that the theoreticians waited; they did not. Very early, Parmenter (Ref 9), Cooper (Ref 10), Douglass (Ref 11), de Gennes and Guyon (Ref 12), and Werthamer (Ref 13) laid down the framework of the theory. By 1964 de Gennes (Ref 14) was able to write a review article explaining the delicate matter of the appropriate boundary conditions.

A fundamental physical quantity that asserts itself in distinguishing thin from thick materials, and single component from heterogeneous structures, is the coherence length. Superconductivity results from electron pair correlation within a certain (temperature and mean free path dependent) distance, the coherence length. The superconducting wavefunction can extend into and through a normal metal. Transition temperatures, critical fields, and critical currents of thin superconducting films are reduced by contiguous normal metals, while the normal metals partake slightly of the superconducting properties. It is to be expected that the superconducting properties of the compound system will depend strongly on the thickness of the normal metal when that thickness is less than the coherence length, but the properties should be independent of normal metal thickness for thicknesses greater than the coherence length. And since the coherence length depends upon temperature, there can be two temperature regimes. In superconducting superlattices we shall see dramatic evidence of the transition between these regimes.

To understand the complicated behavior of layered structures we begin with a review of the relevant properties of single-component, bulk material. We need to understand coherence length, the Ginzburg-Landau (GL) equations, the temperature dependence of the coefficients in those equations, and the significance of the upper critical field. Fortunately, much

of our work has been done for us; a previous issue of this *Scientific Information Bulletin* contains a review article on superconductivity (Ref 15). The GL equations were derived by minimizing the Gibbs free energy with respect to the vector potential A(r) and the quantum mechanical wavefunction ψ(r). In 1950 when Ginzburg and Landau proposed the theory, flux quantization (1961) had not yet been discovered, the BCS theory (1957) did not exist, and Cooper (1956) had not yet demonstrated the instability of the electronic state against the formation of Cooper pairs of electrons with oppositely aligned spins. The Ginzburg-Landau theory was a tour de force of insight. It was not clear what the wavefunction represented--the authors described it as an averaged superconducting electron wavefunction. To patch up the treatment now we consider the charge to be $q = -2e$. Although it is of no consequence, it is appealing to then normalize the wavefunction on one-half the number density of superconducting electrons and consider our pseudoparticle, or pair, to have a mass of 2m, noting that we have been overdefinite since what appears in the treatment is only the ratio ψ/m. de Gennes (Ref 16) comments that "we could just as well have chosen the mass of the sun." In Box 1 we give the GL equations and outline some of their consequences.

CRITICAL FIELD

There is a critical magnetic field H_c. When the external field exceeds H_c superconductivity is destroyed in a type 1 superconductor, to be defined below. The critical field falls quadratically with temperature from its maximum value at 0 K to zero at T_c. This is illustrated in Reference 15. There is

also a critical current. In type I superconductors the critical current is that current which creates the critical field.

The critical field in type I superconductors (Hg, Sn, Al, Zn) is the field at which, if there were no geometric distortions of the magnetic field by shape effects, the superconductor would be transformed into the normal phase. A long cylinder parallel to an external field is converted entirely to the normal state when the field reaches H_c. For other shapes there are demagnetization effects and a gradual conversion over a range of fields. Over this shape-dependent range of fields the superconductor is in the "intermediate state." In the intermediate state the material is permeated by a fine, small-scale network of coexistent normal and superconducting regions. For type I superconductors a typical critical field is 500 gauss. The magnetic energy density, the depression of the superconducting energy below that of the normal state, is then $H_c^2/8\pi = 4 \times 10^4$ ergs/cm^3. This is to be compared with the Fermi energy of about 10^{11} ergs/cm^3. It is astonishing that some of the remarkable properties of superconductors--the critical temperature, the gap width--are rooted in a one-part-in-10^7 effect, and it is assuredly a tribute to the BCS theory (and to Nature, that has been kind to us again and made things simple where they could have been complicated!) that we are able to calculate those phenomena. On the other hand, other phenomena--flux quantization, Meissner effect, infinite conductivity--are a consequence purely of the spontaneous breakdown of electromagnetic gauge invariance and can be derived by a symmetry argument alone once that breakdown is assumed.

Box 1. The Ginzburg-Landau Equations

The first GL equation is the time-independent Schroedinger equation of a pseudoparticle in a magnetic field:

$$\alpha\psi + \beta|\psi|^2\psi + \frac{1}{4m}| - i\hbar\nabla - \frac{2e}{c}A|^2\psi = 0 \qquad (B1-1)$$

It contains an unusual cubic term but can be looked on as a self-consistent Schroedinger equation in which the energy is

$$E = -(\alpha + \beta|\psi|^2) \qquad (B1-2)$$

One can, of course, generalize Equation B1-1 to a time-dependent form, and this is often done.

The significance of the coefficients α and β in Equation B1-1 is found by considering a situation with no currents or magnetic fields and when the wavefunction is constant. The two solutions of Equation B1-1 are $\psi = 0$, the normal state, and $\psi = \psi_o$. With n_s the density of superconducting electrons,

$$|\psi_o|^2 = -\frac{\alpha}{\beta} = \frac{n_s}{2} > 0 \qquad (B1-3)$$

This is the superconducting solution. It will be the lower energy solution when $\alpha/\beta < 0$. We shall return to this when we consider temperature dependence. Equating the energy difference between the normal and superconducting phases to the magnetic energy required to destroy superconductivity one finds

$$\frac{\alpha^2}{2\beta} = \frac{H_c^2}{8\pi} \qquad (B1-4)$$

(H_c is the critical field. See Reference 14 and the CRITICAL FIELD section.) The dimensions of α are energy per particle and of β are energy times volume per particle squared:

$$\alpha = \frac{-H_c^2}{2\pi n_s} \qquad (B1-5)$$

and

$$\beta = \frac{H_c^2}{\pi n_s^2} \qquad (B1-6)$$

continued

> ## Box 1. The Ginzburg-Landau Equations (continued)
>
> The scale of Equation B1-1 is the coherence length ξ. Consider a situation with no currents or magnetic fields but in which the wavefunction need not be uniform, so there is a kinetic energy associated with its curvature. The scale of "stiffness" is set by
>
> $$\xi^2(0) \,\sim\, \frac{-\hbar^2}{4m\alpha} \,\sim\, \frac{\pi\hbar^2 n_s}{2mH_c^2} \tag{B1-7}$$
>
> There is another length scale. The third term in Equation B1-1 reproduces the electromagnetic properties of the London equation and gives the London penetration depth λ, the scale of decay of a static magnetic field into a superconductor because of screening by induced persistent currents (Ref 15).
>
> By means of Equation B1-1 the concept of interface energy can be developed (Ref 15). It turns out (see the following section on upper critical field H_{c2}) that there are two regimes of behavior and classes of materials, depending upon whether the interface energy in a layer at the surface of a superconductor is positive or negative and distinguished by the important Ginzburg-Landau parameter
>
> $$\kappa \,=\, \lambda/\xi \tag{B1-8}$$
>
> The second GL equation describes the current density:
>
> $$j \,\sim\, \frac{-2e\hbar}{4im} (\psi^* \nabla\psi \,-\, \psi \nabla\psi^*) \,-\, \frac{4e^2}{2mc} |\psi|^2 A \tag{B1-9}$$
>
> If there is no external field and the wavefunction is $(n_s/2)^{1/2} \exp(ikx)$, the current density is $(-2e)(v)(n_s/2)$.

UPPER CRITICAL FIELD H_{c2}

Imagine a metal to fill space, but in a uniform magnetic field so strong as to suppress superconductivity. The magnetic field is now reduced to that strength at which the metal just becomes superconducting. The wavefunction will then be weak and we can neglect the cubic term in Equation B1-1. Neglecting the field due to the supercurrent and identifying the vector potential as that of the external field H, Equation B1-1 is the Schroedinger equation of our pseudoparticle in a uniform external field. Classically the particle rotates around the field at the cyclotron frequency

$$\omega_c \,=\, \frac{(2e)H}{(2m)c} \tag{1}$$

Quantum mechanically the allowed levels are the Landau levels, of energy

$$E_n - (n + 1/2)\hbar\omega_c$$

$$+ (1/2)(2m)v^2 \text{ longitudinal} \quad (2)$$

The lowest energy, the $n = 0$ level (and with zero velocity parallel to the magnetic field), occurs at the upper critical field, the field strength at which flux begins to penetrate:

$$-\alpha - (1/2)\hbar\omega_c - \frac{\hbar e H_{c2}}{2mc} \quad (3)$$

Combining this result with the definition of κ (Equation B1-8) and using the relations in Box 1, one arrives at

$$H_{c2} - \sqrt{2}\,\kappa\,H_c \quad (4)$$

By this result we can understand the dichotomy into type I and type II materials alluded to previously. Suppose $\kappa > 1/\sqrt{2}$, so that $H_{c2} > H_c$. As the field is lowered below H_{c2}, field lines enter, and yet the material cannot be completely normal because $H > H_c$. The material is in a mixed state. This is type II behavior. On the other hand, if $\kappa < 1/\sqrt{2}$, $H_c > H_{c2}$. As one reduces the external field, at H_c the material becomes completely superconducting. Above H_c the material was normal; below H_c there is a complete Meissner effect. H_{c2} has no physical meaning. This is type I behavior. The results in Box 1 can also be combined in another form that we shall find useful:

$$H_{c2} - \frac{\Phi_o}{2\pi\xi^2} \quad (5)$$

(Φ_o is the flux quantum, the smallest allowed bundle of magnetic flux. Its value is $ch/2e$, about 2.1×10^{-7} gauss $\times$ cm^2. See Reference 15.) See Box 2 for a discussion of type I and type II superconductors.

Box 2. Type I and Type II Superconductors

Type I Superconductors. $\kappa < 1/\sqrt{2}$. Zn, Cd, Hg, Al, Ga, In, Tl, Sn, Pb.

In simple metals of broad bandwidth the effective mass is small and the Fermi velocity is large. These metals exhibit a Meissner effect, but the field does not drop off exponentially. There are non-local effects due to the "stiffness" of the condensed phase wavefunction over a coherence length.

Type II Superconductors. $\kappa > 1/\sqrt{2}$. Nb, V, Nb_3Sn, Nb_3Ge, V_3Ga, V_3Si, MoRe alloys, some Pb alloys, the new high T_c copper ceramics.

In transition metals and in intermetallic compounds and oxides of narrow bandwidth the effective mass is large, and hence λ is large ($> 2 \times 10^{-5}$ cm). At the same time the Fermi velocity is small ($\sim 10^6$ cm/s) and the energy gap and transition temperature are large (Nb_3Ge has a transition temperature of 22.3 K), so ξ is small (see Ref 15). In the ceramic copper oxides the coherence length is only about 1 nm. Also in disordered alloys, because the coherence length is reduced with the mean free path by the scattering, the London approach is applicable.

CRITICAL FIELDS IN TYPE II SUPERCONDUCTORS: H_{c1}, H_{c2}, H_{c3}

Recall that a long cylinder of type I material in a magnetic field is transformed all at once from superconducting to normal by the critical field H_c. This field strength is a measure of the difference of free energy densities of the normal and superconducting phases:

$$g_n - g_s = H_c^2/8\pi \qquad (6)$$

In type II materials one can consider Equation 6 to be a definition of the critical field strength. The free energy difference can be measured by other means, such as specific heat, and H_c determined. One finds the following phenomena when a type II rod is placed in a longitudinal field:

1. There is a "lower critical field," H_{c1}, less than H_c below which the Meissner effect is complete--there is no flux penetration into the sample.

2. As H exceeds H_{c1} magnetic flux begins to penetrate the sample. The field lines induce persistent currents. The material is superconducting but with an incomplete Meissner effect. With increasing external field more field lines enter the sample until an "upper critical field," H_{c2}, is reached. H_{c2} exceeds the theoretical H_c sometimes by a very large factor. It is this that makes type II materials useful. At H_{c2} the flux penetration is complete and the bulk material is normal. Figure 1 illustrates the induction B as a function of applied longitudinal field strength H in a long, thin wire of type I and type II superconductors. Figure 2 shows $-4\pi M$ [= -(B-H)] versus H.

The integral of M dH is the magnetic energy density stored in the superconductor. It can be shown by a thermodynamic argument that if type I and type II superconductors have the same H_c--the same superconducting energy--the areas under their magnetization curves are the same.
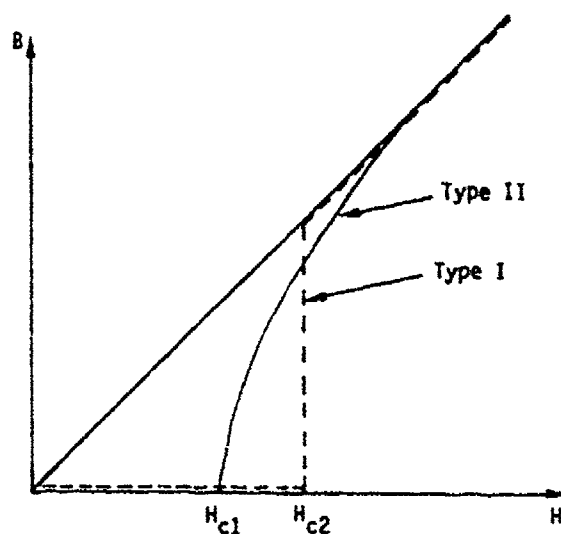
Figure 1. Induction B versus external field H curves for ideal type I and type II superconducting rods in a longitudinal field. The dashed line represents type I behavior and the solid line type II.

3. Above H_{c2}, though bulk superconductivity is gone, if the field is parallel to the surface there remains a surface superconducting layer of thickness $\xi(T)$ up to field strength H_{c3} (Ref 17). $H_{c3} = 1.69$; $H_{c2} = 2.4 \, \kappa \, H_c$. Critical fields are at their maximum at T = 0 K, fall monotonically with increasing temperature, and vanish at T_c. Figure 3 is an (H,T) phase diagram of a long rod of type II superconductor in a longitudinal field.
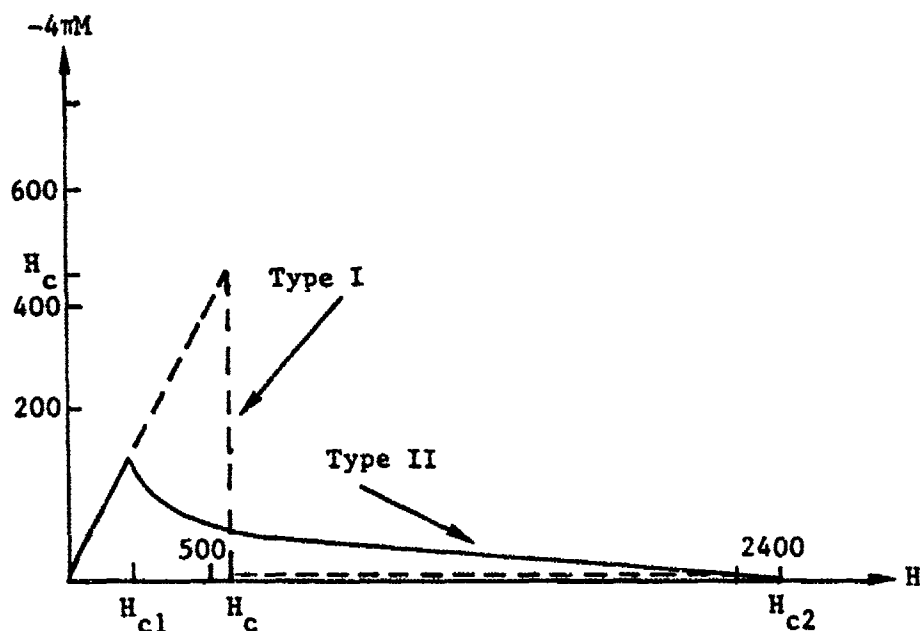
Figure 2. Magnetization versus field curves for type I (dashed) and type II (solid line) superconductors. It can be shown that if the two materials have the same H_c the areas under the two curves are equal.
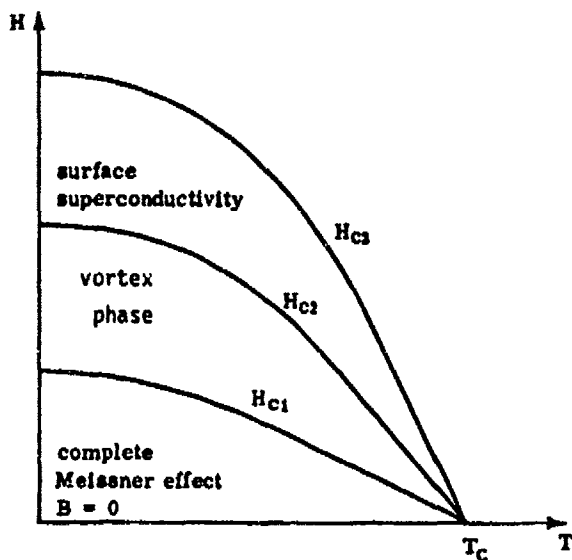
Figure 3. (H,T) phase diagram for a type II superconductor. All three critical fields fall with temperature and vanish at T_c. In the phase below H_{c1} the field is excluded from the sample (on the macroscopic scale; there is a thin penetration layer at the surface in which it falls to zero). Between H_{c1} and H_{c2} field lines increasingly penetrate the material. This is the vortex phase. At H_{c2} there is complete penetration of the field into the bulk. Bulk superconductivity is suppressed by the field, but a superconducting surface layer remains up to field strength H_{c3}.

VORTICES

Between H_{c1} and H_{c2} individual filaments of normal material surrounded by magnetic field lines and current vortices enter the superconductor. The structure of these vortices is understood, particularly in the large λ limit; it is illustrated in Figure 4. Each filament has a narrow (radius ξ) core of normal material. The magnetic field is confined to a range λ around the core, and its strength falls off exponentially from the axis of the core. The field decays with distance because it is screened by a circulating persistent current rotating cylindrically around the core. The filaments are repulsive; they minimize their interaction energy by arranging themselves in a triangular array. (Recall the pores in an anodic oxidized aluminum plate; Ref 18.)
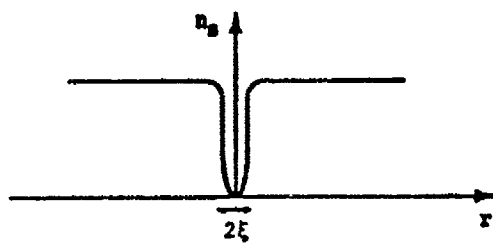
(a) At the axis of the filament is a core of normal material of radius ξ.
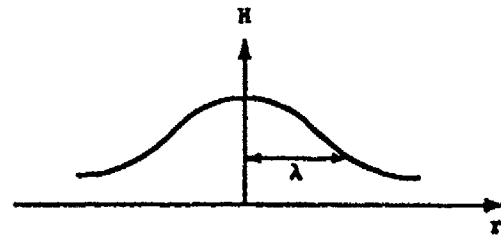
(b) The magnetic field is confined to a cylindrical region of radius λ; its strength decreases exponentially with distance from the axis.
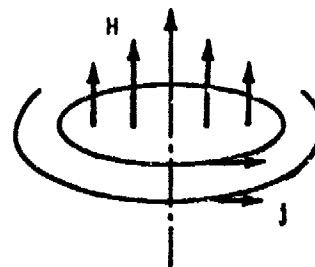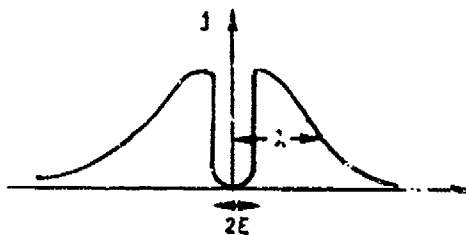
(c) and (d) The field drops off because of screening by a vortex of persistent current. Outside the normal core this current also falls off exponentially with distance from the axis.

Figure 4. A magnetic field filament in a type II superconductor in the vortex state between H_{c1} and H_{c2}. (Adapted from Y.B. Kim, Physics Today, September 1964, pp. 21-30).

TEMPERATURE DEPENDENCE

GL theory is the application to superconductivity of the Landau theory of second-order phase transitions. It is particularly well suited to type II superconductors. The Landau theory (Ref 19) assumes analyticity of the free energy through the second-order phase transition. The theory emphasizes that there is an order parameter that goes to zero continuously at the transition and assumes that the free energy can be expanded near the transition in powers of this order parameter.* The realm of validity of the theory should then be in the neighborhood of the phase transition, where the order parameter is small. And so we must introduce temperature. Return to Equation B1-1 and the discussion following it. When $T < T_c$ one wants the superconducting solution to lie lower in energy; that is, one wants $\alpha/\beta < 0$. When $T > T_c$ one wants the normal $\psi = 0$ solution to lie lower; $\alpha/\beta > 0$. In order to keep the solution bounded one wants β positive. The simplest way to effect this is the assumption introduced by Landau: one sets α proportional to $(T-T_c)$. The coefficient β is presumed to

have a negligibly weak temperature dependence compared with α and is simply taken as constant. The previously introduced $\lambda(0)$ and $\xi(0)$ are the $T = 0$ values of these quantities. This forces the temperature dependence of the other quantities. The program is carried out in Box 3.

ANISOTROPIC EFFECTS, FILMS

One of the earliest suggestions for dealing with bimetal composite films was that of Cooper (Ref 10). Cooper argued that because correlation introduces a non-locality into the electron pair wavefunction the effective interaction should be a spatial average of the attractive potentials on the two sides of the interface. de Gennes (Ref 14) showed that averaging is appropriate only for d_s and d_N both much less than the coherence length, when spatial variation of the order parameter can be neglected. In that case the "effective NV," the interaction energy to be used in the BCS formula for the transition temperature of a bimetal film, is not exactly the simple spatial average Cooper suggested, but is similar to it.

---

*The Landau theory of second-order phase transitions also does much more. It is a symmetry theory. Landau recognized that the symmetry group of the high-temperature disordered phase is of larger order than that of the low-temperature ordered phase; the symmetry group in the ordered phase is a subgroup of that above the transition. The Landau theory rests on the assumption that the free energy is analytic at the phase transition; in point of fact it is not. Relatively large fluctuations in macroscopic parameters alter the behavior from that of classical mean field theory to the "critical exponents" of renormalization group. In magnetism, particularly in systems of low spin quantum number and short range exchange interaction, this leads to short range order persisting far into the paramagnetic regime. But in superconductivity the interaction has long-range components, and deviations from mean field theory behavior are not so large as to invalidate it, except in a narrow temperature range at the transition, and only for those quantities sensitive to short range order, such as the specific heat.

Box 3. Temperature Dependence

We assume that β is a positive constant, to assure boundedness of the solution, and that α is linear in the deviation of T from T_c:

$$\alpha = \alpha' \left(\frac{T - T_c}{T_c} \right) \qquad (B3-1)$$

Then from Equation B1-7,

$$\alpha' = \frac{\hbar^2}{4m\xi^2(0)} \qquad (B3-2)$$

$$n_s(T) = n_s(0) \left(\frac{T_c - T}{T_c} \right); \quad T < T_c \qquad (B3-3)$$
$$= 0 \qquad\qquad T > T_c$$

From Equation B1-5,

$$H_c(T) = H_c(0) \left(\frac{T_c - T}{T_c} \right) \qquad (B3-4)$$

Only near T_c does Equation B3-4 conform to observation, which is better fitted (Ref 20) by

$$H_c(T) = H_c(0)[1 - \left(\frac{T}{T_c} \right)^2] \qquad (B3-5)$$

These are not so different; for small $[(T_c - T)/T_c]$ the empirical relation is approximately

$$H_c(T) \approx 2H_c(0) \left(\frac{T_c - T}{T_c} \right)$$

The temperature dependent penetration depth becomes

$$\lambda(T) = \lambda(0) \left(\frac{T_c}{T_c - T} \right)^{1/2} \qquad (B3-6)$$

Box 3. Temperature Dependence (continued)

The temperature dependent correlation length becomes

$$\xi(T) = \xi(0)\left(\frac{T_c}{T_c-T}\right)^{1/2} \tag{B3-7}$$

Note that κ is independent of temperature as it should be; materials do not switch from type I to type II with changing temperature.

Lastly, we have the important relations

$$H_{c2}(T) = \sqrt{2}\kappa H_c(0)\left(\frac{T_c-T}{T_c}\right) \tag{B3-8}$$

$$H_{c2}(T) = \frac{\Phi_o}{2\pi\xi^2(T)} = \frac{\Phi_o(T_c-T)}{2\pi\xi^2(0)T_c} \tag{B3-9}$$

Saint-James and de Gennes (Ref 17) described surface superconductivity. When a magnetic field perpendicular to the surface is decreased from a high value in a potentially superconducting material, the material becomes superconducting in the vortex state at the same field (Equation B3-9) as in bulk material. But when the field is parallel to the surface, the nucleation field H_{c2par} is increased because of the suppression of circulating currents (see the section on critical fields in type II superconductors discussed previously). Following these ideas, Werthamer, Helfand, and Hohenberg (Ref 21) calculated the upper critical field in the dirty limit (correlation length greater than mean free path).

In thin (quasi-two-dimensional) superconducting films whose thickness d is smaller than the correlation length, the upper critical fields are given, according to Tinkham (Ref 22), by

$$H_{c2perp} = \frac{\Phi_o}{2\pi\xi^2(T)}$$

$$= \frac{\Phi_o}{2\pi\xi^2(0)}\left(\frac{T_c-T}{T_c}\right) \tag{7}$$

$$H_{c2par} = \frac{\Phi_o}{2\pi\xi(T)d/\sqrt{12}}$$

$$= \frac{\Phi_o}{2\pi\xi(0)d/\sqrt{12}}\left(\frac{T_c-T}{T_c}\right)^{1/2} \tag{8}$$

SUPERLATTICES

Dimensional Crossover

The first calculations of the upper critical fields of superconductor superlattices (Ref 3) were by Kats (Ref 23); Lawrence and Doniach (Ref 24); and later by Klemm, Beasley, and Luther (Ref 25) and Deutscher and Entin-Wohlman (Ref 26). H_{c2} was found through application of the anisotropic Ginzburg-Landau equations. Multilayered compounds were modelled as a stack of two-dimensional superconductors, with no variation in the order parameter across each layer, and the layers coupled via Josephson tunneling. The result can be expressed in terms of two coherence lengths, $\xi_{par}(T)$ and $\xi_{perp}(T)$.

The less interesting geometry is when the external field is perpendicular to the layers, for then the orbital currents that circulate in the vortices within each layer do not sense layer thickness. The situation is much like that of a magnetic field perpendicular to the surface of a homogeneous bulk material: the upper critical field is linear in the temperature (Equation B3-9).

When the field is parallel to the surface new things can happen, depending upon the thicknesses of the superconducting and the normal (insulating, semiconducting, or metal) layers and the temperature. Thin ($dN << \xi_{perp}$) layers allow the superconducting layers to couple by Josephson tunneling (insulating or semiconducting layers) and by the proximity effect (metal layers) (Ref 27), and three-dimensional behavior is observed. The Lawrence and Doniach theory (Ref 24) applies:

$$H_{c2perp} = \frac{\Phi_o}{2\pi\xi^2(T)}$$

$$= \frac{\Phi_o}{2\pi\xi^2(0)}\left(\frac{T_c-T}{T_c}\right) \qquad (9)$$

$$H_{c2par} = \frac{\Phi_o}{2\pi\xi_{perp}(T)\xi_{par}(T)}$$

$$= \frac{\Phi_o}{2\pi\xi_{perp}(0)\xi_{par}(0)}\left(\frac{T_c-T}{T_c}\right)$$

$$\qquad \cdots \cdots \cdots (10)$$

But suppose the thickness of the normal layers significantly exceeds the $T = 0$ perpendicular correlation length of the superconductor [$d_N > \xi_{perp}(0)$] and the thickness of the superconducting layers is less than the correlation length [$d_s < \xi_{perp}(0)$]. A phenomenon known as "dimensional crossover" then occurs. At low temperatures the superconducting layers are uncoupled; two-dimensional square root dependence (Equation 8) is observed. As the temperature is increased, $\xi_{perp}(T)$ grows larger than d_N; many superconducting layers are coupled and three-dimensional linear temperature dependence (Equation 10) results.

Dimensional crossover has been observed in naturally occurring intercalated transition metal dichalcogenides (Ref 28) and in artificially grown superlattices--superconductor/insulator Nb/Al$_2$O$_3$ (Ref 29); superconductor/ semiconductor Nb/Ge (Ref 30), Mo/Si

(Ref 31), Pb/Ge, Pb/C (Ref 32); superconductor/metal Nb/Cu (Ref 27), V/Ag (Ref 33), Nb/Ti (Ref 34), Nb/Ag (Ref 35), Nb/Ta (Ref 35), NbTi/Ti (Ref 36); superconductor/ferromagnet V/Ni (Ref 37); and superconductor/ superconductor Nb-Ti/Nb (Ref 36, 38).

In earlier work surface superconductivity obscured the results. Surface conductivity can be suppressed by depositing sufficiently thick ($\approx$300 nm) coatings of a good normal conductor such as copper on the outermost surfaces. Figure 5 shows standard three-dimensional behavior in a thick (850 nm) Nb film. Perpendicular and parallel upper critical fields are the same; they decrease linearly with increasing temperature up to the critical temperature. In Figure 6 we show (Ref 1) the two critical fields in a Nb layer whose thickness (19 nm) is less than the bulk correlation length ($\xi_{Nb} \approx 40$ nm). While the perpendicular critical field shows no indication of reduced dimensionality, the parallel critical field displays typical two-dimensional character. Figure 7 shows dimensional crossover. Within the thick outer copper layers there is a superlattice of alternately Nb (17.1 nm) and Cu (37.6 nm). At all temperatures H_{c2perp} varies as (T_c-T), since $\xi_{par}(T)$ is not affected by dimensional change (Ref 32). On the other hand, at lower temperatures, when ξ_{perp} is smaller than d_{Cu} but exceeds d_{Nb}, H_{c2par} varies as in a two-dimensional film. But as the temperature increases ξ_{perp} exceeds d_{Cu}, the superconducting layers are coupled together, and the temperature dependence is linear (Ref 1).
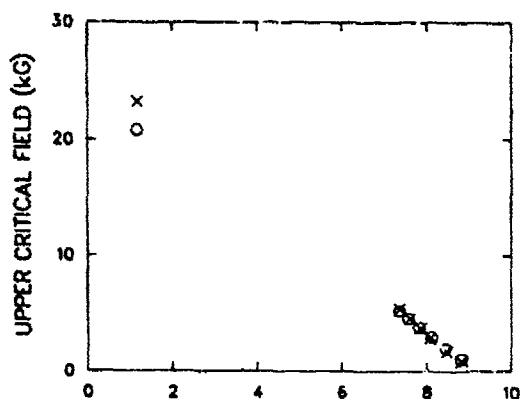
Figure 5. Upper critical fields versus temperature of a thick niobium film. The thickness of the Nb layer (850 nm) greatly exceeds the Nb correlation length (= 40 nm). The single layer of Nb is covered with thick (300 nm) layers of Cu to suppress surface superconductivity. The upper critical fields show typical three-dimensional behavior; H_{c2perp} and H_{c2par} are equal and fall linearly with increasing T up to T_c.

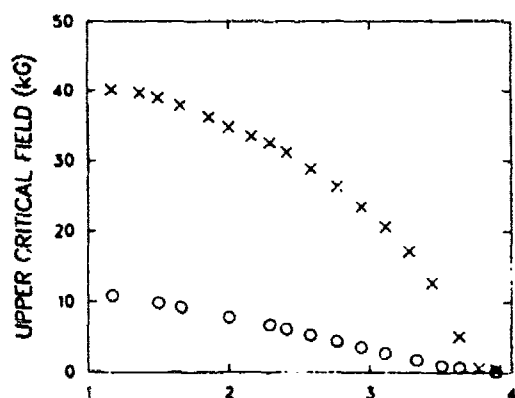Figure 6. Upper critical fields versus temperature of a thin niobium film. Within the outer thick Cu layers is a single sheet of Nb whose thickness (19.1 nm) is less than the Nb correlation length (= 40 nm). This is a typical two-dimensional situation; H_{c2par} exceeds H_{c2perp}. H_{c2perp} varies linearly with (T_c-T), but H_{c2par} falls with increasing temperature as $(T_c-T)^{1/2}$.
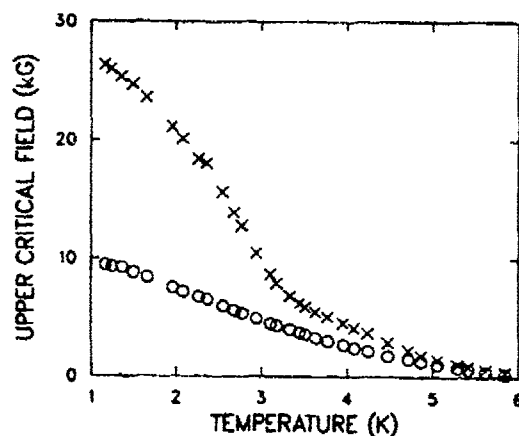
Figure 7. Dimensional crossover in a niobium/copper superlattice. The thickness of the Nb layers (17.1 nm) is less than the $T=0$ Nb correlation length (≈ 40 nm). The Cu layer thickness (37.6 nm) in the superlattice is about the same as the Nb correlation length. H_{c2perp} varies as (T_c-T) at all temperatures. At low temperatures the Nb layers are uncoupled, and H_{c2par} depends on temperature as the square root. But at higher temperatures ξ_{Nb} greatly exceeds d_{Cu}, the layers couple together, and linear temperature dependence results.

Proximity Effects, Ferromagnetism, Complications

To this point we have been able to employ only an appealingly simple theory, an effective mass theory, in which the order parameter is treated as uniform in the superconducting layers, and with the layers coupled only by Josephson tunneling (Ref 24). But when layer thickness exceeds the coherence length the order parameter is nonuniform. Proximity effects must be taken into account. Density of states at the Fermi level, electron diffusivities, mean free paths, Debye temperatures, all can be expected to differ in the materials constituting the superlattice. As is to be expected, as

the theory has matured complications have been progressively attacked and included and new experimental features have been discovered and analyzed.

The most complete and detailed treatments are those of Tachiki and Takahashi (Ref 39) and of Biagi et al. (Ref 40) on the perpendicular upper critical field. Tachiki and Takahashi extend the treatment of de Gennes and Guyon (Ref 12) and de Gennes (Ref 14) to include proximity effects through normal metal layers. They allow the densities of states to differ in the two components, as well as the conduction electron diffusion constants. To treat superconductor/magnetic superlattices Tachiki and Takahashi include the effect of spin polarization of conduction electrons in the ferromagnetic layers.

There are four kinds of superconductor superlattices to be considered: Josephson coupled, in which the normal material is an insulator (Ref 29) or a semiconductor (Ref 30-32); proximity coupled, in which the normal layers are metallic (Ref 27, 33-36); magnetic (Ref 37); and superconductor/superconductor (Ref 34, 36, 38).

Dimensional crossover was understood for Josephson-coupled superlattices, and Schuller had proposed that the same phenomenon would occur in proximity-coupled superlattices. Tachiki and Takahashi (Ref 39) have calculated this. They find the same qualitative behavior as in Josephson-coupled superlattices. Their theory is now confirmed in quantitative detail in Nb/Cu (Ref 1, 27) and by the measurements of Kanoda et al. (Ref 33) on V/Ag, Nakajima et al. (Ref 34) on Nb/Ti, and Ikebe et al. (Ref 35) on Nb/Ag and Nb/Ta. Dimensional crossover progresses systematically with the ratio of the density of states of the superconductor and the separator.

In all experiments on superlattices up to this point the parallel upper critical field was larger than the perpendicular upper critical field. In superconductor/magnetic superlattices in a temperature range just below T_c, H_{c2par} is less than H_{c2perp}. This has been observed by Homma et al. (Ref 37) in V/Ni superlattices and explained, at least qualitatively, by Takahashi and Tachiki (Ref 39). Magnetization measurements show that the conduction electron spin polarization in the Ni layers is highly anisotropic; the spin polarization induced by a magnetic field parallel to the layer is far larger than that induced by a perpendicular field. Thus, the pair breaking field due to the spin polarization is greater when the external field is parallel to the layers than when it is perpendicular. At high temperatures near T_c the coherence length is large, the vortices extend over many layers, and H_{c2par} is more greatly reduced by the pair breaking field in the nickel than is H_{c2perp}. But as the temperature is reduced the coherence length shrinks to less than the layer thickness and the vortices lie within the nickel layers in the parallel field configuration. The situation is then not very different from that in a nonmagnetic superlattice: H_{c2par} again exceeds H_{c2perp}.

Superconductor/superconductor superlattices merit particular attention. Takahashi and Tachiki pointed out that another source of dimensional crossover is possible when the two components have different diffusion constants D. Just below T_c the coherence length is large and many layers are coupled. Other things being equal, the order parameter nucleates preferentially in the set of layers of large D. The low diffusion constant of the dirty layers tends to confine the pair potential to the high D layers. At lower temperatures the order parameter shifts to the dirty layers

and is confined there by the short coherence length. The layers uncouple. Obi et al. (Ref 36) observed a break in slope of H_{c2par} in NbTi/Nb.

The measurements of Karkut et al. (Ref 38) on NbTi/Nb superconducting superlattices also conform to the Takahashi and Tachiki theory and to plausible expectation. The thicker the layers the higher the temperature at which layer thickness exceeds coherence length, and the higher the temperature at which the break in slope should occur. This is shown in Figure 8, from Karkut et al. (Ref 38).

Dimensional crossover can manifest itself in another way. While H_{c2perp} is insensitive to layer thickness, H_{c2par} is enhanced when ξ_{perp} is less than the layer thickness. The T = 0 K anisotropy ratio, $H_{c2par}(0)/H_{c2perp}(0)$, should then peak at a thickness something like the coherence length. For simplicity consider $d_s = d_N = d$. Figure 9 is from Takahashi and Tachiki (Ref 39). Layer thickness d is plotted in units of coherence length. Height and position of the maximum shifts to lower d/ξ for lower ratios of normal to superconducting density of states. Banerjee et al. (Ref 27) observed a sharp peak in H_{c2par}/H_{c2perp} in Nb/Cu superlattices. Figure 10 is from Obi et al. (Ref 36). It shows the low temperature (1.5 K) ratio of the two upper critical fields measured on two NbTi/Ti multilayers. One of these, designated N TT1, is $Nb_{65}Ti_{35}/Ti$; the other, NTT2, is $Nb_{28}Ti_{72}/Ti$. The abscissa is the modulation wavelength of the superlattice ($d_s = d_N = \Lambda/2$). The authors interpret the shift to a higher peak at lower layer thickness as evidence for a higher density of states in the superconducting layers of the more Nb-rich material (a lower N_N/N_s), in support of the Takahashi and Tachiki theory. But at the same time, measurements (Ref 36) on NbTi/Nb fail to conform to the theory.
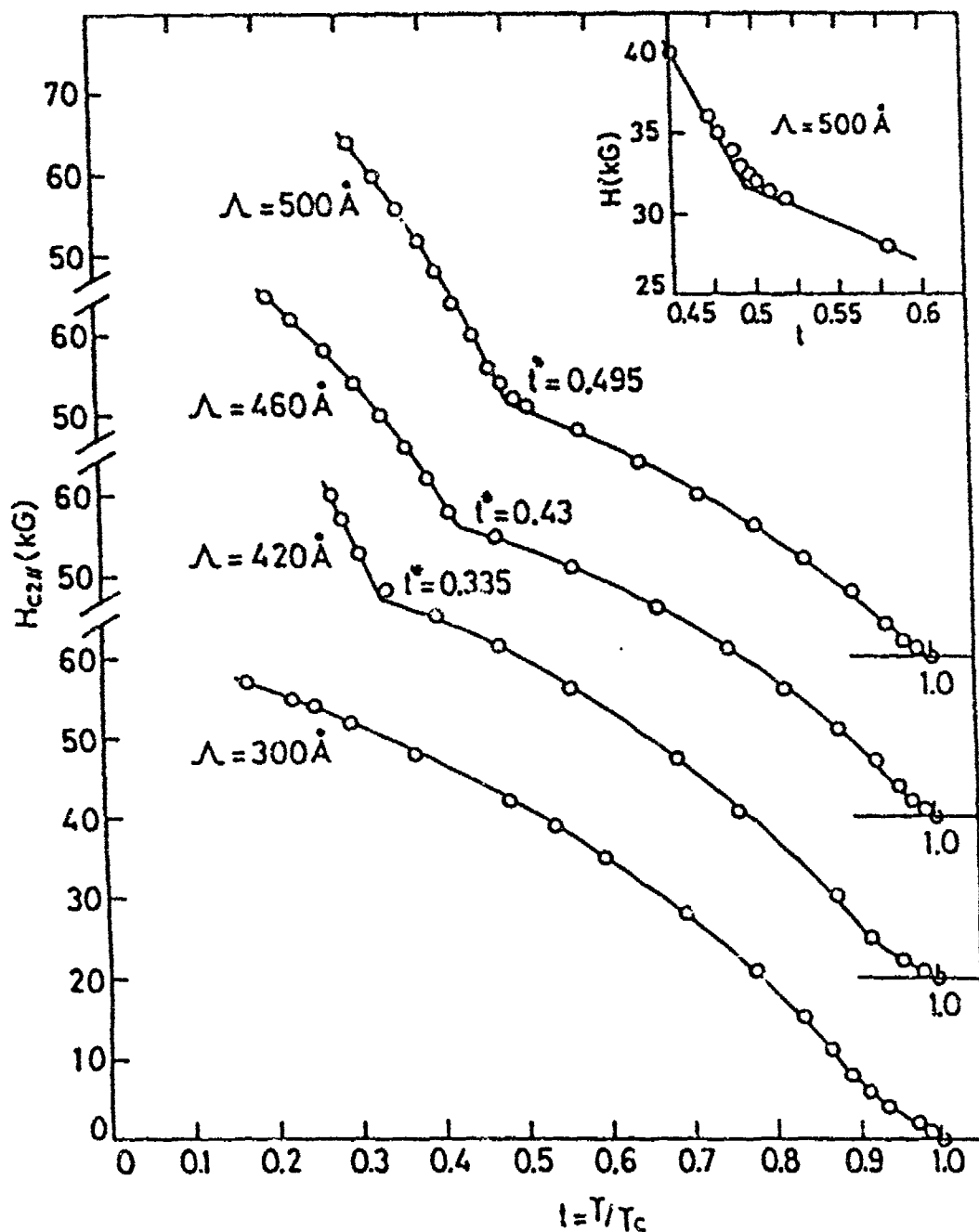
Figure 8. $H_{c2\parallel}$ versus t ($= T/T_c$). Dimensional crossover in a superconductor/ superconductor superlattice. The two components, $Nb_{65}Ti_{35}$ and Nb, have approximately the same T_c; they differ principally in electron diffusion constants. D of the disordered alloy is expected to be much less than that of the pure metal ($D_{NbTi}/D_{Nb} = 0.048$). $\Lambda = d_{NbTi} + d_{Nb}$. t^* ($= T^*/T_c$) is the reduced temperature at which the break in slope occurs. The y axes are displaced for clarity and the solid lines are guides to the eye. Blowup for the region around t^* for the $\Lambda = 500$ Å sample (from Ref 38).
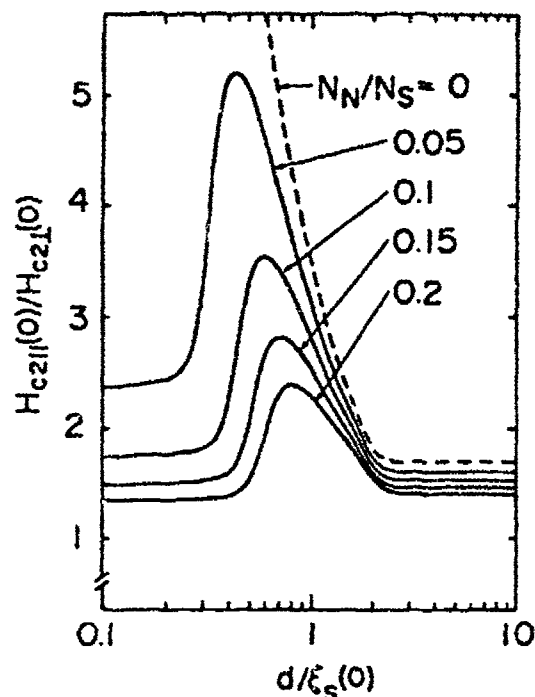
Figure 9. Ratio of H_{c2par} to H_{c2perp} at T = 0 K as a function of layer thickness $d = d_N = d_S$. Thickness is normalized on the coherence length $\xi_S(0)$. Curves show several ratios of densities of states at the Fermi level of the normal and superconducting materials. The figure is from Reference 39 and the dashed curve conforms to Reference 17.

Figure 10. Anisotropy ratio of upper critical fields, H_{c2par}/H_{c2perp}, as a function of superlattice repeat distance ($\Lambda = 2d$; $d = d_S = d_N$) at 1.5 K. NTT1 = $Nb_{65}Ti_{35}/Ti$; NTT2 = $Nb_{28}Ti_{72}/Ti$. NTT1 presumably has a higher density of states at the Fermi level, N_S (and therefore a lower N_N/N_S), than NTT2 (from Ref 36).

CERAMIC SUPERLATTICES: THE FUTURE

How about high T_c ceramic super-conductor superlattices--with each other, with conventional superconductors, with normal metals and semiconductors? About the only thing we know about high T_c super-lattices is that they will be made. Tonouchi et al. (Ref 41) of Osaka University have fabricated up to five alternate layers of yttrium-barium-copper oxide, erbium-barium-copper oxide, and others. Multi-layers with 1.5 nm thick layers and with 60 nm layers have been produced.

Depending upon the oxygen defect concentration, the ceramic oxides have the electronic transport properties of insulators, semiconductors, metals, or superconductors. One of their many mysteries is that though they do not look metallic--they are not shiny--they have metallic, linear temperature dependence of resistivity over a very wide temperature range above T_c. Who knows what electronic devices it will be possible to make from ceramic superlattices? The coherence length in the oxides is extremely short-- about 1 nm, a lattice constant. This must change the physics. What happens in con-tiguous superconductors with different

mechanisms for Cooper pair formation? The Josephson effect has been observed. How about proximity effects and dimensional crossover--are they different? The future is surely full of surprises.

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OPPORTUNITIES FOR LONG-TERM RESEARCH VISITS AND OTHER RESEARCH CONTACTS WITH JAPAN

National Science Foundation*
Division of International Programs
American Embassy, Tokyo, Japan

To improve the professional relationships between American and Japanese scientists and institutions, the National Science Foundation is implementing a "Japan Initiative Program" beginning in 1988.

Experience in Japan has long indicated that, despite that country's technical prowess, relatively few American scientists and engineers spend time in Japan during their graduate education or conducting scientific research. As a result, professional relationships between American and Japanese scientists and institutions lack the breadth and depth of those with scientists from European countries, so results from Japanese laboratories often take longer to diffuse into American laboratories than do those from European counterparts.

In an effort to increase the number of U.S. investigators conducting research in Japan, the National Science Foundation (NSF) is implementing a "Japan Initiative Program," beginning in 1988. The goals of the initiative are:

• To increase the number of scientists and engineers in the United States who can operate with ease in Japan's research community and follow developments in the Japanese science and engineering literature

• To increase American recognition of the potential benefits of cooperative research with Japanese institutions

• To build relations between the U.S. and Japanese research communities

NSF will accomplish these goals in the following ways:

1. Provide funds for scientists and engineers to undertake long-term research stays (6 months or more) in Japan.

Recipients of long-term research grants will receive a monthly stipend, round-trip airfare (for themselves and up to three accompanying dependents) to Japan, and a modest housing allowance. Although

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the program is primarily aimed at scientists and engineers embarking on their research careers, it also will consider proposals from senior researchers for sabbaticals or other long-term research visits to Japan.

2. Provide fellowships for scientists and engineers at the graduate, post-graduate, and senior levels to study the Japanese language; help develop better curricula and course materials for teaching Japanese to such students.

NSF will support Japanese language study aimed at facilitating a researcher's stay in Japan or at developing the ability to read Japanese technical literature. This program supports only language study, not travel to Japan; the program announcement (NSF 88-10) gives further details. Application deadlines are 15 May, 15 October, and 15 December. NSF will also accept proposals to develop improved course materials for teaching technical Japanese.

3. Identify and secure opportunities for American researchers at Japanese research institutes, including corporate facilities.

NSF will assist U.S. researchers in arranging long-term stays at Japanese laboratories. The NSF office in Tokyo will continue to elicit commitments from Japanese companies to accept qualified American researchers. The office can also contact Japanese labs, both national and private, to facilitate replies to applications from U.S. scientists and engineers.

4. Fund survey teams to visit Japan, to report on the state-of-the-art in specific disciplines, with an emphasis on opportunities offered in Japan for U.S. researchers to advance their work.

NSF's International Information and Analysis section (INT/I&A) accepts proposals to collect information on the state of research abroad on selected topics. See I&A's separate brochure (NSF 87-67) for details.

NSF hopes to send 10 to 15 researchers in 1988 and plans gradually to expand the long-term fellowship program. Language fellowships could number 40 or 50 in the first year and increase to twice that number in subsequent years.

On its own initiative, the Japanese Government offers other support for U.S. researchers in Japan. Taken together, those programs will significantly expand U.S. researchers' opportunities to work with their Japanese colleagues in Japan.

In January 1988, Prime Minister Takeshita announced that the Government of Japan would provide $4.8 million to the National Science Foundation for the formation of a Japan-U.S. Science Fellowship Fund to increase the number of American researchers going to Japan. The U.S. investigators select the Japanese laboratories, whether government, private, or industrial, at which they wish to conduct research for periods of 6 months or more.

The Japan Society for the Promotion of Science (JSPS) annually offers 50 post-doctoral fellowships for U.S. scientists and engineers to conduct research at Japanese university laboratories or at

other institutions affiliated with the Japanese Ministry of Education, Science, and Culture. Twenty-five candidates will be nominated by NSF and 5 by the National Institutes of Health (NIH); 20 more will be directly invited by Japanese professors. Those research visits will normally last 1 year.

A parallel program, sponsored by the Japanese Science and Technology Agency (STA), will support about 50 young U.S. researchers yearly at any Japanese national laboratory except those affiliated with universities, as well as at Japanese public corporations and certain nonprofit research foundations. NSF will act in a coordinating role for the U.S. Government in selecting 35 of the candidates. Of these, NSF will select 20, NIH will select 5, and 10 positions will be allotted to other science and technology agencies of the U.S. Government to send researchers under their employment.

Moreover, on 1 June 1988, NSF and the Agency of Industrial Science and Technology (AIST), of the Ministry of International Trade and Industry (MITI), signed a Memorandum of Understanding whereby AIST will provide access to its research institutes each year for up to 30 U.S. scientists and engineers. The visits, which will be funded by NSF, will normally last from 6 months to 1 year.

Finally, in June 1986, NSF and the Institute for New Generation Computer Technology (ICOT) signed a Memorandum of Understanding whereby up to three researchers per year may be sent to ICOT for periods of 6 months to 1 year. For further information on this program contact Dr. Y.T. Chien, Director, Division of Robotics and Intelligent Systems, NSF, telephone 357-9572, or the International Programs Division address listed below.

For further information on all of the programs mentioned above, including application forms, contact NSF at the following address:

Division of International Programs
National Science Foundation
Washington, DC 20550

ATTN: Japan Initiative

TEL: (202) 357-9558
Electronic Mail: cwallace@note.nsf.gov

For information regarding NIH applications, contact:

Dr. Bettie Graham or Dr. Lynn Arende
International Research and Awards Branch
Fogarty International Center
National Institutes of Health
Bethesda, MD 20892

TEL: (301) 496-6688

THE INTERNATIONAL SYMPOSIUM ON ENDOTOXIN

Jeannine A. Majde

*E*ndotoxin is a bacterial cell wall component with a plethora of biological actions, some of them potentially beneficial. This symposium focused on the structural features of this complex class of molecules that determine its toxic versus its immunostimulatory properties.

The International Symposium on Endotoxin took place at the Jichi Medical School in Tochigi, Japan, on 11-13 May 1988. It was organized as a satellite symposium to the Fourth International Conference on Immunopharmacology in Osaka. While this meeting constituted the first formal meeting of the newly formed International Endotoxin Society, endotoxin has formed the basis for large international gatherings for some 30 years. In view of recent developments in the field, it is appropriate that this particular meeting took place in Japan.

Endotoxin is a component of the cell wall of Gram-negative bacteria that is generally blamed for many of the toxic manifestations (sepsis and shock) associated with the Gram-negative infections that kill 50,000 Americans per year. At the same time, endotoxin is recognized as a potent immunostimulant with potential applications ranging from serving as a vaccine adjuvant to treating cancer patients. Endotoxin and related bacterial cell wall products leaching from the intestine may also serve as physiological regulators of such general body functions as temperature and sleep. The enigmatic, and often dramatic, actions of endotoxin have intrigued investigators since the 1930s, but its highly complicated structure evaded clarification until about 1984. It is now known that endotoxin is a complex lipopolysaccharide containing unique sugars and fatty acids together with two critical phosphate groups responsible for many of its toxic manifestations. Much of this information stems from elegant chemical analysis in Germany combined with direct synthesis achieved in Japan. The principals involved in these chemical studies as well as a number of biologists probing its modes of action met in Tochigi to continue the analysis of this intriguing molecule. About 200 registrants attended the meeting, roughly half of whom were from Japan.

The first day of the meeting was devoted to the chemistry of endotoxins (actually, the plural is more appropriate because each Gram-negative organism has a unique endotoxin with unique immunological properties). In simplest terms, the basic endotoxin molecule can be divided into three functional regions: (1) the variable terminal polysaccharide, which serves as the antigenic determinant for Gram-negative bacteria; (2) the core polysaccharide, which is unique in sugar composition and fairly constant in all Gram-negative bacteria; and (3) the hydrophobic lipid A terminus containing two phosphorylated galactosamines bound to a complex array of acyl groups. The lipid A region, which is responsible for the toxicity

and most other physiological properties of the molecule, was the focus of the chemistry presentations. With the advent of synthetic and highly purified endotoxins with well-characterized lipid As, many workers have attempted to determine the structural requirements for the wide range of their biological activities. The various derivatives synthesized by T. Shiba of Osaka University have been used by a group headed by S. Kotani (recently retired from Osaka University) to determine which sugar, phosphate, and acyl substitutions account for induction of such activities as fever, cytokine synthesis, eicosenoid synthesis, serum complement activation, slow-wave sleep induction, interaction with *Limulus* lysate, toxicity for chick embryos, etc. About eight specific derivatives have been screened in carefully standardized systems, a formidable undertaking that is slowly revealing the lipid A structure with the most desirable properties (efficacy without toxicity) for use as an immune stimulant. Acyl group configurations appear to determine whether a particular lipid A will be toxic or immunostimulatory; the activities can be separated (J. Homma, Kitasato Institute, Tokyo, Japan).

These biological analyses are nicely complemented by chemical studies on lipid As at Freiburg and Borstel, FRG. H. Mayer of Freiburg University has isolated endotoxins from more exotic bacteria (most previous work has been conducted with *E. coli* and salmonella species) and characterized them with mass spectroscopy; he has found that the terminal sugars may vary in such organisms as brucella. E. Th. Rietschel's group at the Borstel Research Institute has used very sophisticated chemical techniques to derive some general principles of endotoxin toxicity: for instance, the melting temperature of the acyl side chains is critical as is the physical configuration in solution. The phosphate groups are critical for immunogenicity as well as toxicity. D. Jacobs of the University of Buffalo finds that nontoxic lipid As fail to intercalate into the cell membrane, a step that is probably essential for calcium ion flux perturbation. The existence of a lipid A receptor is still controversial, but its capacity to bind to the C_{1q} component of complement which, in turn, binds to macrophages may serve as a functional binding site (M. Loos, Johannes Gutenberg University, Mainz, FRG). Binding of endotoxins to macrophages is stimulated by gamma-interferon or interleukin-3 through the lipid A component (K. Akagawa, NIH, Tokyo). Whole endotoxin (the natural form released from bacterial cell walls *in vivo*) is carried in the serum by low density lipoprotein (LDH) and thus is selectively taken up by cells with receptors for LDH; macrophages and adrenal cortex cells are selective targets (M. Freudenberg, Max Planck Institute, Freiburg, FRG).

The consequences of endotoxin association with cells (whether through a specific receptor or simply chemical intercalation) simulate the effects of calcium ionophores, a phenomenon originally observed by D. Morrison (currently of the University of Kansas) about 1979. M. Nakano, Jichi Medical School, Tochigi (the host of the meeting), has shown that the interleukin-1 (IL1) response (a critical physiological mediator, or cytokine,

induced by endotoxins) can be induced by calcium ionophores as well, but this fails to occur in mice genetically incapable of responding to endotoxins. The calmodulin pathway rather than the phosphokinase C pathway appears to be defective in these mice, which suggests that calmodulin, a critical intracellular signal transducer, may be the primary mediator of endotoxin's effects.

At the pathophysiological level, it has recently been demonstrated that cytokines such as IL1, and particularly tumor necrosis factor (TNF), may be the mediators of the shock response to endotoxin. C. Galanos of the Max Planck Institute has analyzed the relationship of TNF to endotoxin tolerance and shown that depletion of TNF by low-dose endotoxin can explain the tolerance phenomenon. Endotoxin sensitivity, which can be enhanced by adrenalectomy or various liver toxins, also seems to be due to enhanced sensitivity to TNF. TNF is made largely by macrophages, which accounts for the critical role of this cell type in endotoxicity.

Other mediators important in endotoxicity are the eicosenoids. These products of membrane arachidonic acid include the prostaglandins, leukotrienes, and lipoxins, which often represent the actual effector molecules in a biological event. The lipoxins currently appear to be important effectors of macrophage secretion of IL1, while prostaglandins drive macrophage secretion of collagenase (U. Schade, Borstel Institute). These observations have important implications for the design of antiinflammatory drugs more selective for the destructive features of inflammation (such as collagen degradation). A new

lipoxin, 13-hydroxyoctadecadienoic acid or 13-HODD, is stimulated in macrophages by endotoxins and may prove to be an important mediator of one of endotoxin's many actions (U. Schade, Borstel Institute).

On the practical side, measuring endotoxin in clinical material has previously relied on a test developed in 1964 that uses a gelation response, evaluated visually, of a lysate of white cells from the horseshoe crab Limulus polyphemus. In fact, all pharmaceuticals for human or veterinary use must be tested for endotoxin contamination (pyrogens) by this method. Substantial advances in Japan have been made to automate this process in order to improve its specificity (any polyanion will potentially gel Limulus lysate), sensitivity, and objectivity. These methods have allowed the analysis of the presence of endotoxemia in clinical states where endotoxin has long been thought to play a role, such as septic shock, as well as in such conditions as viral hepatitis (van Deventer, Academic Medical Center, Amsterdam). These methods should help resolve long-standing arguments regarding the role of endotoxins released from the intestines in a number of disease states.

An innovative and very promising method of measuring endotoxin was described by K. Tanamoto of the National Institute of Hygienic Sciences, Tokyo, that uses fluorescent labeling of the beta-hydroxy myristic acids unique to lipid A. The method is sensitive to 5 femtomoles of myristic acid. He also indicated that mass spectroscopy of these fatty acids might provide a sensitive and unique marker for endotoxins.

A final practical issue discussed at the end of the conference related to the use of detoxified endotoxins for immunotherapy. This application has driven commercial interest in endotoxins for many years and remains the "holy grail." (The 32 Japanese companies that sponsored this meeting are probably all inspired by this "grail.") Substantial progress has been made recently by a small U.S. firm named Ribi ImmunoChemicals in Hamilton, MT. Their detoxified monophosphoryl derivative of lipid A has shown great potential for serving as a vaccine adjuvant and, when combined with another microbial substance (trehalose dimycolate), as a stimulant of nonspecific resistance in cancer patients and other immunocompromised individuals.

Dr. Jeannine A. Majde is the Program Manager for Systems Biology at the Office of Naval Research (ONR) in Arlington, VA, where she currently serves as Scientific Officer for immunology, cell biology, neurophysiology, and medical materials. Her formal training is in virology and immunopathology and she currently conducts research in viral toxicity mechanisms and physiological regulation of macrophage-virus interactions in defined culture systems. She has developed ONR programs in immunopharmacology, physiological regulation of the immune system, and cell biology of trauma and is engaged in managing the exploratory development and industrial transition of two medical materials (a blood substitute called liposome-encapsulated hemoglobin and a therapeutic for ischemia called oligo-prostaglandin B). In her 16-year career with ONR she has received numerous performance awards and the Navy Meritorious Civilian Service Award for her contributions to the Navy Blood Program.

THE FOURTH INTERNATIONAL CONFERENCE ON METAL-ORGANIC VAPOR PHASE EPITAXY

N. Bottka and D.K. Gaskill

The conference, held in Hakone, Japan, focused on the latest developments in metal-organic vapor phase epitaxy (MOVPE) growth technology with emphasis on large-scale production of high-speed electronic devices and synthesis of group III-V, II-VI, III-V on IV materials, and high T_c superconducting films.

INTRODUCTION

The Fourth International Conference on Metal-Organic Vapor Phase Epitaxy (ICMOVPE-IV) was held in Hakone, Japan, on 16-20 May 1988. Previous conferences were in 1981 (Corsica, France); 1984 (Sheffield, England); and 1986 (Los Angeles, U.S.A.). Hakone had 422 participants representing 20 different nations. Out of these about one-third were from outside Japan. The United States had 57 representatives. There were 9 invited and 135 contributed papers; half of the contributed papers were presented in the poster format. Topics included growth mechanisms, source materials, new growth techniques, characterization, device applications, mismatched systems, narrow- and wide-gap materials, and quantum wells.

This report focuses on the following topics: (1) historical perspectives and the success of MOVPE in large-scale production of high-speed devices, (2) highlights on new material systems, (3) current problems with doping, and (4) future challenges.

BACKGROUND

First, some general remarks about metal-organic (MO) epitaxial technology to set the stage for the details to come. MOVPE is an epitaxial growth technique used in the fabrication of homo- and heterojunction structures of semiconductors such as GaAs, InP, AlGaAs, HgCdTe, ZnSe, etc. It includes commensurate systems such as AlGaAs on GaAs and incommensurate lattice systems such as GaAs on Si and strained layer superlattices. MOVPE has promise in becoming the leading technology in producing (on a large scale) the next generation of high-speed integrated circuits (IC), high-frequency microwave/millimeterwave devices, and new electrooptic components. It is safe to say that MOVPE has fulfilled many of the promises envisioned by the early workers in this field and is now the leading materials growth technology for most non-Si-based semiconductors. Progress in MOVPE becomes apparent when viewing the field from a historic perspective. For example, just 4 years ago at Sheffield, one of the key topics at that conference was reactor design and achievement of good heterojunction abruptness. What was then considered a breakthrough (one-monolayer abrupt change in composition) is now almost routine among serious practitioners of the art. What was then considered an achievement in high electron mobility transistors (HEMT) (transconductance of 177 and

342 mS mm^{-1} at 300 and 77 K, respectively) is now overshadowed by new successes, not only in AlGaAs/GaAs-based HEMT, but also in structures based on the InAlAs/InGaAs and InGaP/GaAs material systems. Much of this success is due to better understanding of the complex MOVPE process, better reactor design, and purer source materials. But much still needs to be done. The challenge for the next decade will not only be technological but also economical (see the discussion at the end of this report).

MOVPE IN LARGE-SCALE PRODUCTION OF HEMTs

Large-scale production of HEMT structures for high-speed digital and high-frequency analog applications is a true measure of maturity of the MOVPE technology (and a good example of the Japanese dominance in III-V technology). J. Komeno from Fujitsu Laboratory presented an invited paper on this subject showing mass-production results on AlGaAs/GaAs- and InGaP/GaAs-based HEMT structures. Two type of reactors were described: (1) a two-3-inch-wafer, 760 torr horizontal reactor with dual rotation for susceptor/substrate and (2) a six-3-inch-wafer, 76 torr bell-jar system with rotating susceptor. In the horizontal reactor the growth conditions for AlGaAs/GaAs were as follows: growth temperature T_g = 660 °C, H$_2$ flow 16.5 SLM, growth rate 9.5 Ås^{-1}, V/III = 25 (70) for GaAs(Al$_x$Ga$_{1-x}$As), and x = 0.23. The resulting values for sheet carrier density n$_s$ (cm^{-2}) and mobility μ (cm^{2}V^{-1}s^{-1}) were: 1.06 x 10^{12}, 6,900 at 300 K; 9.4 x 10^{11}, 49,000 at 77 K; and 9.1 x 10^{11}, 604,000 at 4.2 K, respectively. Within-wafer uniformity was as follows: n$_s$ and μ, ±2.5 percent; thickness,

d, ±2 percent; carrier concentration, N, ±1.5 percent; and composition, x, ±1 percent. Wafer-to-wafer uniformity for all the above parameters was ±1 percent. Enhanced (depletion) mode threshold voltages were -1.160 ±0.035 V (-0.060 ±0.023 V). The cutoff frequency was 23 GHz. In the horizontal reactor, InGaP/GaAs was grown at 630 °C with thickness and carrier concentration variation less than ±1.5 and ±4.5 percent, respectively. In the bell-jar reactor the growth conditions for AlGaAs/GaAs were as follows: T$_g$ = 650 °C, growth rate of 6.7 (1.8) Ås^{-1} for GaAs(AlGaAs), and H$_2$ flow 50 SLM. Within-wafer uniformity for thickness and carrier concentration was ±2.1 (±1.6) percent and ±2.0 (1.2) percent parallel (perpendicular) to the flow direction, respectively. These are impressive figures, but are they good enough to make HEMT-based ICs competitive with Si-based IC technology? The consensus was no, at least not for very large scale integration (VLSI) digital application. The HEMT-based VLSI demands severe control on key parameters: spacer thickness $\Delta d/d$ = ±0.6 percent, $\Delta N/N$ = ±1.2 percent, $\Delta x/x$ = ±1.3 percent, threshold voltage ΔV_{th} = ±10 meV, and defect count less than 2/cm^2. For a typical HEMT structure this translates into control of spacer layer thickness and carrier concentration of ±3Å and ±5 x 10^{15} cm^{-3}, respectively. A tall order for any epitaxial technology!

NEW MATERIAL SYSTEMS

Because of low temperature I-V instability of the AlGaAs/GaAs-based HEMT structure (seen in many laboratories and believed to be due to the so-called DX-centers in the AlGaAs material),

a number of researchers have been exploring new material systems for HEMT application. Y. Mori from Sony Corporation reported on an AlInAs/InGaAs heterostructure with measured two-dimensional electron gas (2DEG) mobilities of 12,400 and 76,900 $cm^2V^{-1}s^{-1}$ at 300 and 77 K, respectively. FETs with gate length of 0.7 μm fabricated from these structures showed a transconductance of 680 and 870 mS mm^{-1} at 300 and 77 K, respectively. These are the highest values among FETs ever reported using InGaAs as channel layer. Similar work at Allied Bendix Aerospace reported by L. Aina resulted in 308 mS mm^{-1} and 11.5 dB gain at 10 GHz. T. Ohory from Fujitsu reported on a HEMT structure (for IC application) based on the InGaP/GaAs material system that had room temperature transconductance of 250 mS mm^{-1} for a 1-μm gate. The device was stable at low temperature operation and had threshold voltages of 0.4 (-0.5) V in enhanced (depletion) mode. This is a very encouraging result because the InGaP-based material is preferred (over AlGaAs-based material) for large-scale fabrication.

There were only two papers on heterojunction bipolar transistors (HBT), both based on the InP/InGaAs(P) (instead of the AlGaAs/GaAs) material system. HBT is an important device for IC application because of its high speed, high current handling capability, and high current gain at low collector current levels. R. Bhat from Bell Communication reported on InP/InGaAs HBT with a maximum current gain of 5,000 at a current density of 1,000 A cm^{-2}. This is the highest gain reported for this material system and surpasses the previous value of 1,300 for devices grown by molecular beam epitaxy

(MBE). It should be noted that because of the lower bandgap of the base material [E_g = 0.78 (InGaAs) versus 1.42 eV (GaAs)], lower emitter-base voltage is required for a given collector current. This allows higher frequency of operation for a given power dissipation. Another advantage of InP/InGaAs over AlGaAs/GaAs is the lower surface recombination in the emitter region of InP. The larger surface recombination of the AlGaAs emitter limits current gain for a small area (high frequency) HBT. Unfortunately, Bhat did not measure the cutoff frequency (f_c) of his HBTs. Y. Ban from Opto-Electronic Laboratory, Japan, did report a f_c of 3.6 GHz for a collector current of 20 mA in a InP/InGaAsP HBT. The ominous absence of AlGaAs/GaAs-based HBT papers at Hakone probably indicates that the technology is considered (at least by the Japanese) to be mature enough for VLSI production.

The Plenary Session opened with a message by Dr. M. Razeghi titled "MOVPE Challenge for the Future Photonic and Electronic Devices." The list of successes by the Thomson-CSF group is impressive: high quality InP with 77 K mobility of 200,000 $cm^2V^{-1}s^{-1}$ and $N_d - N_a$ = 3 x 10^{13} cm^{-3}; observed 2DEG and quantum Hall effect in InGaAs/InP, InGaAsP/InP, and GaAs/GaInP heterostructures; 2DHG (hole gas) in InGaAs/InP; laser emitting at 1.3 μm, with I_{th} of 10 kA cm^{-2} from a InGaAsP/InP structure grown on Si (which was preseeded with a thin GaAs layer and a strain layer superlattice buffer). The laser exhibited a longer lifetime, 24 hours, than any other laser structure grown on Si (the longest cw operation AlGaAs/GaAs laser on Si lasted 4 hours).

R.D. Dupuis from AT&T Bell Laboratory gave an invited talk on the mismatched GaAs on Si system that summarized the state-of-the-art. The bad news is that the large residual stress and dislocation density in the film (10^6 cm^{-2}) still limits GaAs/Si for minority carrier device applications. InP on Si fares somewhat better in spite of the larger lattice mismatch between InP and Si (8 percent) as demonstrated by the successful operation of an InP-InGaAsP-InP DHJ laser by the Thomson-CSF group mentioned above. The improved performance of this quaternary-based laser may be due to the lower thermal expansion difference between InP and Si. Many of the participants felt that much improvement needs to be achieved before these mismatched systems can be considered for device fabrication. There is also the need to develop the growth of GaAs and InP on insulating substrates such as SOS and SOI. This would lead to potential application in microwave devices.

The highlight on II-VI materials [and the idiosyncrasy of MCT (HgCdTe)] was presented by J.B. Mullin from RSRE. Uniform and reproducible MCT requires careful control both in the Hg vapor pressure and the growth temperature (T_g) (both parameters affect composition and background acceptor concentration); low T_g is also desirable to reduce Hg diffusion. T_g values as low as 200 °C have been achieved by substituting (t-Bu)$_2$-Te for diethyl-Te (the Te-bearing MO source determines the lower limit on T_g). One percent compositional uniformity over 1 in^2 in MCT has been achieved at RSRE both on CdTe and CdTe/GaAs. Control on doping and heterojunction abruptness is, however, still a problem.

CURRENT PROBLEMS WITH DOPING

Most of the wide-gap II-VI papers dealt with the ZnSe and ZnS material systems. These are of interest because of their potential application as blue light emitting diodes. One of the problems is p-doping. It is difficult to find a suitable shallow acceptor. A. Ohki from NTT reported on p-ZnSe using nitrogen as a dopant (ionization energy of N is about 100 meV). The highest doping achieved was p = 1.4×10^{15} cm^{-3}. A. Yoshikawa from Chiba University reported on p-ZnSe using cyclopentadienyl-Li (CpLi) as a doping source. The activation energy of the Li acceptor was estimated from photoluminescence (PL) to be about 100 meV. No carrier concentration data were given. An interesting poster paper on ZnS$_x$Se$_{1-x}$/GaAs was presented by T. Konda from Hiroshima University. By using PL and Rutherford back scattering (RBS), he showed that interface diffusion occurs abruptly above the critical film thickness when $0 < x < 0.045$ and $x > 0.075$ (lattice mismatch condition). There was no observable interdiffusion for perfect lattice matching. This finding has serious implications for heterojunction-based device structures. Misfit dislocations at interfaces may place fundamental limitations on composition and doping abruptness.

The lack of a good, general-purpose p-type dopant still plagues MOVPE. In most cases Zn, from DMZn, is used and heterostructure growth is changed to accommodate its inherent problems (such as diffusion). But, as Dr. Ohba and coworkers demonstrated, the maximum hole concentration from Zn-doping in DH

lasers consisting of GaInP and AlInP is insufficient for optimum device performance (2×10^{18} and 2×10^{17} cm^{-3}, respectively). They examined the properties of Mg-doping using Cp$_2$Mg in the above material systems and found enhanced hole concentration for GaInP (1×10^{19} cm^{-3}) but no improvement for AlInP. The lack of improvement in AlInP is due to a decrease in electrical activation as the incorporation level increases, opposite of the effect in GaInP. Even this modest improvement in doping is offset by the added technical and engineering burden of memory effects when using Cp$_2$Mg in an MOVPE reactor, as Dr. Landgren and coworkers demonstrated. Additionally, the electrical activation of the standard p-dopants may be sensitive to growth conditions according to the controversial report by Dr. Nelson's group at British Telecom Research Laboratories concerning the effect of PH$_3$ and AsH$_3$ on the electrical activation of p-dopants (Zn and Cd) in InP. It was found that a PH$_3$ ambient during the final minutes of epitaxial growth yields nearly 100 percent electrical activation, but an AsH$_3$ or AsH$_3$/PH$_3$ ambient results in reduced activation, in some cases as low as 10 percent, even with layers capped with p-GaInAs! The cause of this effect is not clear, though complexes of H with Zn or Cd were proposed to play a role. It should be noted that C can also be used as a p-dopant, as demonstrated by epitaxial GaAs growths using trimethylarsenics (TMAs) and triethylarsenics (TEAs). But as Dr. Speckman's, Dr. Araki's, and Dr. Brauers's talks demonstrated, the morphology of the layers suffered considerably in these applications, maximum hole concentrations were limited to the high 10^{17} or about 1×10^{18} cm^{-3}, and impurities in MO-sources were a problem.

GROWTH MECHANISMS

A most stimulating session was on growth mechanisms. Much progress (theoretical and experimental) has been made in the last few years in understanding the gas phase decomposition and reaction mechanisms taking place in MOVPE. R. Pollard from the University of Houston presented a sophisticated theoretical model explaining the elementary processes and rate-limiting steps in MOVPE. His analysis includes 60 species and 230 reactions in the gas phase and 22 species and 124 elementary processes at the surface. Model predictions agree with experimental data obtained for a wide range of operating conditions such as the observed dependence of growth rate on inlet gas composition and the influence of crystallographic orientation on carbon incorporation rates. Success in such modeling depends on knowledge of the reaction paths and rate constants.

Experimental work (to a large extent funded by the Office of Naval Research and the Air Force Office of Scientific Research) at the Naval Research Laboratory, University of Southern California, University of Minnesota, University of Utah, and AT&T has contributed significantly to this knowledge. One of the authors of this article (D.K. Gaskill) presented a paper on the use of infrared (IR) diode laser spectroscopy to probe in-situ and in real-time the MOVPE environment. The focus of this study was on the arsine-methyl radical reaction kinetics. By using tunable IR diode laser transient absorption spectroscopy to measure the methyl radical concentration versus time we were able to determine the bimolecular rate constant for this reaction at 304 and 440 K. K. Jensen from the University of Minnesota reported

on in-situ mass spectroscopy studies of the decomposition of MO arsenic compounds in the presence of trimethyl- and triethyl-gallium. The results were as follows: (1) t-Bu-As has a lower decomposition temperature than TMAs (560 versus 690 K); (2) both trimethyl-gallium (TMG) and TMA decomposed via a similar unimolecular reaction involving the loss of methyl groups whereas the triethyl-gallium (TEG) compound decomposed through a beta-elimination step at high temperature [this is not the case for triethylarsenics (TEAs)]; and (3) the primary decomposition path of t-Bu-As also follows a beta-elimination process, resulting in the in-situ production of arsine and isobutene being the main hydrocarbon product. R.M. Lum from AT&T presented results on growth mechanism studies of GaAs from TMAs and TMG using ^{13}C isotope labeling (on the TMAs) to obtain direct evidence on how the alkyl reactants used in MOVPE affect the growth and impurity incorporation reaction. Post-growth SIMS measurements of the ^{13}C concentration show that carbon increased with increasing growth temperature but was independent of the V/III molar ratio. An increase in film carbon content was also observed as the misorientation angle from the (100) substrate plane was decreased from 6 to 0 degree.

It is interesting to note the entry of metal-organic chemical vapor deposition (MOCVD) as a method for producing superconducting films. A late newspaper by Dr. Abe and coworkers from OKI Electric Company reported the growth of Y-Ba-Cu-O superconducting films with a maximum T_c of 60 K, surpassing the 20 K mark recently reported by a Naval Research Laboratory (NRL) team. The OKI group also used beta-diketonates as Y,

Ba, and Cu sources, heating them for transport in Ar and reacting them over a MgO substrate at 600 °C in an ambient pressure oxygen atmosphere. The source temperatures were reported as: 130 to 160 °C for Y, 260 to 300 °C for Ba, and 140 to 170 °C for Cu. At a rump session, Dr. Gaskill reported that the NRL team had been successful in producing a thin Bi-Sr-Ca-Cu-O film with T_c = 73 K, extending the earlier beta-diketonate work. These developments indicate the potential that MOCVD has in growing thin superconducting films. Future developments in this line of research will be worth observing.

FUTURE CHALLENGES

There was a rump session dealing with MOVPE as a mass-production technique and with modulation structures and new materials. Dr. Kawai from Sony Corporation gave an overview as to where we are heading with the MOVPE technology. His prognosis was that HEMTs for digital VLSI application are very questionable because of the severe demands on uniformity mentioned before. HEMTs for analog and MIMIC applications look much more promising. HBTs and SISFETs have a future for very high speed digital as well as analog and MIMIC applications. The big question in everybody's mind was: Where is the market? Dr. T. Suzuki from NEC summarized this market concern succinctly by pointing out that the CD-player industry's needs for laser diodes can readily be satisfied by a single MOVPE reactor producing three 2-inch wafers per day! The market for electro-optic devices based on InP/InGaAs/InAlAs material may fare better in the future provided the cost per device can be reduced. The envisioned

driving forces are optical communication, microwave and millimeterwave, solar cells, and high performance electronics.

What are the implications to the United States and the Department of Defense? As with many other technologies, we seem to have given up our lead to the Japanese in the area of III-V based electronics. Not because we lack innovation, but because we lack the long-term commitment to III-V materials research. We need to focus our efforts much more and foster a more cooperative environment within the research and development community if we hope to compete with the Japanese. This means long-term funding in key III-V technologies, more university-industry-government synergy, more scientific exchanges with Japanese institutes, and more on-site visits of Japanese laboratories.

Nicholas Bottka received his B.S. (1963) and M.S. (1966) in applied physics at the University of California at Los Angeles and his Ph.D. (1970) in physics at the Technical University of Berlin. Since 1983 he has been a research physicist, section head, in the Chemical Deposition Section at the Naval Research Laboratory (NRL) doing work related to organometallic vapor phase epitaxy (OMVPE). Dr. Bottka has an additional 20 years of experience as a research physicist at the Naval Weapons Center, Research Department, China Lake, CA. He is a co-inventor of modulation spectroscopy and related optical characterization tools used to study the band structure of solids. Dr. Bottka's current interests include infrared diode laser absorption spectroscopy as applied to the study of OMVPE growth kinetics and reactor design improvement. He is a member of the American Physical Society, Sigma Pi Sigma, and the Scientific Research Society of America. In 1987 Dr. Bottka was awarded the NRL Alan Berman Publication Award.

David Kurt Gaskill received his B.S. in physics at Eastern Illinois University in 1977, M.S. in physics at the University of Illinois in 1979, and Ph.D. in condensed matter physics at Oregon State University in 1984. He was awarded a National Research Council/Naval Research Laboratory Cooperative Associateship for 1984-1987. Dr. Gaskill joined NRL as a research physicist in 1987. His professional interests include the growth and kinetics of semiconductors and superconductors by OMVPE and the characterization of these materials, especially by modulation spectroscopy. He has published over 20 articles and received the Alan Berman Award at NRL in 1987.

THE SIXTH CHINESE TITANIUM SCIENTIFIC CONFERENCE

Hidetake Kusamichi

Although China's titanium industry is small, it is supported by a wide variety of domestic demands. This article describes the status of China's titanium industry and discusses the prospects for the industry's future as it heads toward internationalization.

INTRODUCTION

The Sixth Chinese Titanium Scientific Conference was held under the auspices of the China Nonferrous Metal Society, National Scientific Technical Committee, General China Nonferrous Metals Industrial Corporation, and the Titanium Research and Development Center, at Hsiaosai Hotel in Hsian from 17-21 September 1987, with more than 300 titanium specialists from China and other parts of the world invited. The Titanium Conference was first held in 1972 in Baoji and has thereafter been held in such cities as Kuangchou, Shangnai, Shenyang, and Beijing once every 3 years.

What was new in this Titanium Conference was that specialists were invited for the first time from abroad to be recognized for their contributions to China's titanium industry. Invited from France were Prof. P. Lacombe (chairman, Sixth International Titanium Conference) and Dr. R. Tricol (Cezus/Pesinne Group); from West Germany, Prof. G. Luetjering (vice chairman, Fifth International Titanium Conference); from the United States, Dr. J.A. Hall (Garrett Turbine Engine Co.); and from Japan, the author (vice chairman, Fifth International Titanium Conference).

On September 17th and 18th a plenary session was held; the speakers included 5 foreign guests, 6 guests, and 10 Chinese titanium researchers, a total of 21 speakers. The subjects of the speeches and names of the speakers are listed in the Appendix.

STATUS OF CHINA'S TITANIUM INDUSTRY

China's titanium industry has a 30-year history. It has followed a thorny path but at present seems to have established a secure foundation. Especially, the development of the industry since the Fifth Chinese Titanium Scientific Conference has been remarkable.

Resources and Production of Titanium Sponge

China has abundant titanium resources, leading the world in reserves. Ten billion tons of proved ore reserves contain about 800 million tons of TiO_2. This will be a crucial factor in the development of China's titanium industry.

The Mg reduction process is becoming a popular refining process in China as elsewhere. The current production capacity is 3,000 tons annually. More than 90 percent is first- and second-class titanium sponge used in the titanium metal industry.

In comparison with the most advanced technologies on an international scale, it cannot be denied that China's titanium-sponge production technique lags behind. For example, power consumption rates are high but furnace capacities are small, and the sponge typically contains large amounts of impurities, especially, high contents of iron and oxygen. This is disadvantageous in the application of China's titanium sponge to plate-type heat-exchanger sheet. In addition, the sponge particle size is large. These factors mean that Chinese titanium sponge does not fully meet the requirements of melting shops. Recently, however, significant improvements have been made, and excellent results are being obtained.

Major subjects of study in the production of titanium sponge in China include the following:

1. Continuous melting of high-titanium slag in closed electrical furnaces

2. Production of synthetic rutile by dilute hydrochloric acid leaching

3. Production of titanium tetrachloride from high-titanium content slag using a new fluidized method called chlorination

4. A process combining reduction and distillation of titanium sponge

Perfection of these techniques will greatly further the development of China's titanium industry.

At one time titanium sponge was also produced by the Na reduction process. Titanium produced by this process has excellent features, such as fine particle size and low levels of impurities such as nitrogen, iron, and carbon; however, due to large amounts of chloride ion and dust in the titanium sponge and other drawbacks, production has been suspended. No other production process of titanium sponge, including molten salt electrolysis, has yet been brought into practical use.

Titanium Melting and Casting

China's titanium is primarily melted in the vacuum consumable-arc melting furnace located in the melting shop of Baoji Nonferrous Metal Works. Other nonferrous metal works and iron and steel works also have titanium-ingot production capacity. The annual production of titanium ingots in China is 3,000 tons. An ingot measuring 711 mm diameter by 3.3 tons produced by Baoji Nonferrous Metal Works is the biggest titanium ingot to date in China.

Since 1980 consumable electrodes have been produced by plasma welding. Recently, the surface quality of titanium ingots has been remarkably improved. The yield, which was 89 percent in the past, has been improved to 93 to 98 percent. Extensive research has resulted in production of sound ingots of 6A1-4V titanium alloy free from internal segregation. However, at present it is difficult to eliminate segregation in titanium-alloy ingots containing high-density elements, and further investigations are required.

Titanium skull melting and casting furnaces have been operating since 1964. The largest of such furnaces has a capacity of 200 kg, but most are in the 25-60-50-kg class. Molds are primarily made from graphite, which is either machined or rammed with synthetic resin bond. Water-soluble sand molds have been also put to practical use.

Titanium castings are used for valves and pumps in the chemical industry. Experimentally, they are being applied to aircraft and marine parts for the Navy with good results. Precision casting has reached the practical application stage. Engineers have studied graphite/press forming (PF) and ceramic-shell moldings, and now a number of prototype models are being tested for aircraft applications. Processing techniques for hot isostatic pressing have also been investigated, and the quality of precision castings has significantly improved.

Recovery and Recycling of Titanium Scrap

A recycling technique for various titanium scraps has been established, in which 18 percent scrap is added to commercially pure titanium ingots. This technique has allowed 1,000 tons of titanium scrap to be recycled, thus increasing the effective metal utilization rate. In addition to consumable-electrode arc furnaces, plasma skull furnaces are used to recover titanium scrap. Electron-beam melting furnaces and the hydriding process have also been used in the recycling of titanium scraps.

Production of Titanium Mill Products

Annual production of mill products has exceeded 1,000 tons. Table 1 lists 18 alloys in commercial production and 17 alloys in trial production. Shapes and sizes of China's titanium mill products are shown in Table 2, indicating that they have not yet reached levels that can satisfy market demands. More than 80 percent of mill products are commercially pure titanium, but the Chinese have acquired the technique and know-how to produce titanium alloys in accordance with requirements.

Techniques for direct extrusion of the oxidization ingot, removal of oxidized skin by electrolysis, warm rolling for tubing, Ti-Cu composite bar, explosive bonding and rolling and others, not to mention regular production processes, have been already utilized. More than 500 tons of titanium-steel clad plates have been produced by rolling explosive-bonded materials. Production techniques of pure Ti seamless tubes have met the world standard.

Research and Progress in New Alloys and Techniques

Research on the 6A1-4V titanium alloy in China is advanced. At present, BT-9, Ti-679, Ti-230, Ti-7A1-4Mo, BT3-1, Ti-4A1-3Mo-1V, Ti-3A1-2.5V, Ti-5621S, Ti-0.2Pd, Ti-0.3Mo-0.8Ni, Ti-32Mo, and Ti-451 are being investigated.

Table 1. China's Titanium and Titanium Alloys

Nominal Composition	Type	Designation
Commercial Alloys		
Iodide titanium	α	
Commercial pure titanium 1	α	TA_1
Commercial pure titanium 2	α	TA_2
Commercial pure titanium 3	α	TA_3
Ti-0.2Pd	α	
Ti-3Al	α	
Ti-4Al-0.005B	α	
Ti-5Al	α	TA_6
Ti-5Al-2.5Sn	α	TA_7
Ti-6Al-2.5Sn-3Cu-1.5Zr	α	
Ti-2Al-1.5Mn	$\alpha + \beta$	TC_1
Ti-3Al-1.5Mn	$\alpha + \beta$	TC_2
Ti-5Al-4V	$\alpha + \beta$	TC_3
Ti-6Al-4V	$\alpha + \beta$	TC_4
Ti-6Al-5Cr-2.5Mo-0.5Fe-0.3Si	$\alpha + \beta$	
Ti-6Al-0.6Cr-0.4Fe-0.4Si-0.01B	$\alpha + \beta$	
Ti-6.5Al-3.5Mo-2.5Sn-0.3Si	$\alpha + \beta$	TC_9
Ti-6Al-6V-2Sn-0.5Cu-0.5Fe	$\alpha + \beta$	TC_{10}
Ti-8Cr-5Mo-5V-3Al	β	TB_2
Alloys in Trial Production		
Ti-2.5Cu	α	
Ti-0.3Mo-0.8Ni	α	G-12
Ti-8Al-1Mo-1V	near-α	BT-15
Ti-11Sn-5Zr-2.25Al-1Mo-0.25Si	near-α	Ti-679
Ti-5Al-6Sn-2Zr-1Mo-0.25Si	near-α	Ti-5621S
Ti-7Al-4Mo	$\alpha + \beta$	BT-9
Ti-6Al-2.5Mo-2Cr-0.5Fe-0.3Si	$\alpha + \beta$	TC-11
Ti-4Al-3Mo-1V	$\alpha + \beta$	
Ti-3Al-2.5V	$\alpha + \beta$	
Ti-5Al-4Mo-4Cr-2Sn-2Zr	$\alpha + \beta$	
Ti-4.5Al-5Mo-1.5Cr	$\alpha + \beta$	
Ti-10V-2Fe-3Al	$\alpha + \beta$	Ti-10-2-3
Ti-10Mo-8V-1Fe-3.5Al	β	
Ti-10V-7Mo-2Fe-1Zr-4Al	β	
Ti-15Mo	β	
Ti-32Mo	β	
Ti-11.5Mo-6Zr-4.5Sn	β	β-III

Table 2. Variety and Specifications of Ti and Ti Alloy
Mill Products Currently in China

Variety	Specifications in mm
Plate and Sheet Cold rolled	0.3 x (400-1,000) x 3,000 (0.5-4.0) x 1,000 x 3,000
Hot rolled	(4.0-10.0) x 1,000 x 3,000 (8.0-30.0) x 2,000 x 3,000
Strip and Foil	(0.1-0.3) x (100-320) x L (0.01-0.09) x (100-320) x L
Biscuit	diameter $\leq$ 600, thickness $\geq$ 40
Rod and Bar Extruded bar Rolled rod Forged rod	(ϕ12-100) x L (ϕ8-60) x L max. ϕ250, swaged bar ϕ3-ϕ5
Tubing Welded tube Extruded tube	(ϕ2-120) x 11,000 (ϕ18-210) x L
Wire	(ϕ0.1-6.0) x L

In research on high-temperature titanium alloys, alloys with excellent creep resistance and thermal stability at 550 °C have been developed by the addition of a trace amount of rare-earth metal to near-α Ti alloy. Ti-633G, Ti-55311S, and HTi-2Y are the current types. As shown in Table 3, they correspond to IMI-829. The theory of electron concentration is used to control the thermal stability of alloys. Also, the shape-memory alloy of Ti-Ni has reached the stage where it can be used commercially.

A great number of studies are required for new alloy development, but many of the studied alloys cannot be successfully applied and, therefore, are not being produced.

In China, research and development of new techniques, including near-net shape, precision casting, isothermal forging, powder metallurgy (P/M) forging, superplasticity forming, and diffusion bonding, is very popular. Many researchers presented papers on such technologies at this conference.

An isothermal forging technique for TC11 has been put into practical use to produce compressor disks and other parts for actual engines. Complex-shaped pneumatic pump hatches are being produced on a trial basis through superplastic forming and diffusion bonding and have already been installed and tested in aircraft.

Table 3. Principal Properties of Heat-Resistant Titanium Alloy
Under Experiment in China

[Note: Data for IMI-829 are the ones measured at 540 °C.]

Property	Ti-633G	Ti-55311S	HTi-2Y	IMI-829
At Room Temperature				
Tensile strength, MPa	975	1,040	1,135	950
Yield strength, MPa	829	932	--	820
Elongation, %	13.6	11	12.5	9
Reduction of area, %	25	19	23.3	18
At 550 °C				
Tensile strength, MPa	632	736	852	590
Yield strength, MPa	504	500	--	460
Elongation, %	15.9	15	11.4	12
Reduction of area, %	35.5	48	37.7	25
Held at 500 °C for 100 Hours				
Creep deformation, %	0.144	0.15	0.154	0.1
MPa	300	300	274	300
After Held at 550 °C With 300 MPa for 100 Hours				
Tensile strength, MPa	1,018	1,049	1,169	950
Yield strength, MPa	1,000	970	--	820
Elongation, %	12.3	7	7.3	7
Reduction of area, %	18.6	12	10.8	12

In the field of powder metallurgy, high-quality, low-oxygen alloy powder was prepared through plasma rotating electrodes and hydrogenizing and dehydrogenizing techniques. It was confirmed that properties of this trial sample, which was subsequently subjected to hot isostatic pressing, were almost equivalent to those of products produced by the melting process.

Among studies of various new materials and new technologies, it is worth international notice that China has succeeded in developing titanium microporous material after 10 years of extensive studies. As representative mill products of this material, there are welded and seamless tubes, plates, tape, and various specially shaped products. In the course of developing this material, P/M rolling, hydrostatic pressing, and other techniques were developed and brought into practical use. The material has excellent properties, including high strength and hardness and heat and corrosion resistance. It also has excellent vibration absorption capacity and weldability and can be applied in many fields. Further improvement of processing techniques and cost reductions will result in even more uses for this new material.

Titanium Applications

In China, titanium was first applied to aircraft, but recently, as shown in Table 4, it has been incorporated in space development equipment. Aircraft components for which titanium alloys have been used or will be applied in the near future are as follows:

- Engine disks, blades, and other components are made of TC6 and TC11 alloys, which are expected to be mass produced soon.

- TA7 alloy rings, die forgings, and plates are used for engine shells, rotation basements, and supporting liners and partitions of rack basements.

- TC4 alloy is successfully used for frames of fuselages and TB2 and Ti22 alloys for rivets.

Titanium applications in fields other than for aircraft were planned from the middle of the 1970s.

Table 5 shows the present ratio of titanium equipment in China's chemical industry. The soda (chlorine) industry accounts for the largest percentage. Table 6 classifies this titanium equipment and shows the percentages: heat exchangers account for 47.3 percent, followed by containers, towers, and tanks. The remainder are pumps, electrodes, and blowers, in that order.

Table 4. China's Ti Alloys and Application Area
Used in Space Development Equipment

Alloy	Application Area
TC4	Gas cylinder and frame for satellite and rocket
TC6	Tail jet hydraulic cylinder
TC11	Disc and blades
TA7(d)	Front cartridge receiver of communication satellite
TB2	Connecting strap between satellite and rocket
2T3	Casted cartridge receiver support
2T4	Casted cartridge receiver support

Table 5. Percentage of Ti Equipment Applied in the Chemical Industry

Department of Chemical Industry	Percentage
Soda industry (including potassium industry)	25
Chemical fertilizer and fiber	18
Inorganic and plastic chemistry	20
Basic organic synthesis chemistry	15
Dyestuff intermediate	4
Fine chemical industry	3
Others	15

Table 6. Ti Equipment Used in the Chemical Industry

Equipment	Percentage
Heat exchangers	47.3
Vessels	32.5
Pumps	15.9
Electrodes	2.4
Blowers	1.9
Total	100.0

If utilization of 1 ton of titanium yields 50,000 yuan ($13,200 or about ¥2 million), China has earned profits of 130 million yuan ($34 million or about ¥5 billion) for half of 1986. Utilization of 1,000 tons of titanium per year has yielded profits equal to about ¥2 billion. In 1983, a National Conference to Broaden Applications of Titanium Material was held to encourage applications throughout China. Since then, demand for titanium has steadily increased, with the aforementioned results.

Figure 1 shows the transition in shipments of titanium mill products per year, with 1980 set to 100. In 1983, shipments were increased by 44 percent, in 1984 by 30 percent, and in 1985 by 42 percent, for an average increase of 40 percent per year. It is certain that a steady increase was achieved in 1986, and further increases were expected in 1987.

PROSPECTS FOR CHINA'S TITANIUM INDUSTRY

After 30 years of hard work, the foundation of China's titanium industry has been solidified. With the progress of the seventh 5-year plan, it will achieve further prosperity. Titanium production will increase to 2,000 tons from the demands of the soda, chemical fertilizer, organic and synthetic chemical, and P/M industries.

Titanium applications in the fields of electrodes, ships, ocean development equipment, seawater desalination equipment, petroleum refineries, vehicles, and construction, all of which are popular in the West, will also provide a great potential market in China. During the sixth 5-year plan, titanium applications to aircraft will steadily increase. In the seventh 5-year plan, the steady efforts now being made by titanium researchers in China will bear fruit, and shipments of titanium material will increase by 50 percent. By the end of this century, they will have increased 1 to 1.5 times. By then, China's titanium industry will have attained the current international level from the technical and economic points of view.

China has abundant titanium resources. If technologies, resources, and demands can be skillfully coordinated, the future of the titanium industry is very promising. Its development will make a substantial contribution to the development of China's economy. In this way, titanium will tread the path of the third metal, both nominally and commercially.
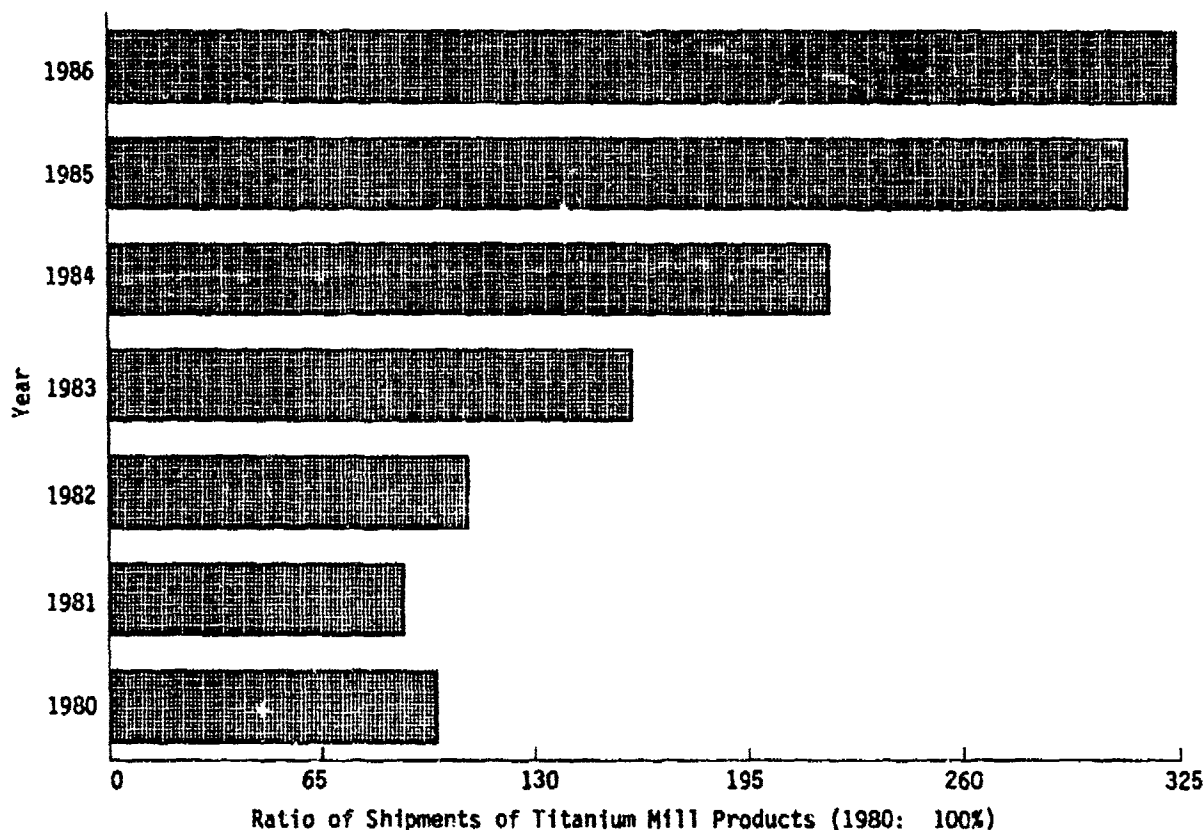
Figure 1. The transition in shipments of titanium mill products per year.

The following sections are the author's general views on what China's titanium researchers and other people in the field might contribute towards the future.

Expanding Titanium Applications

Reviewing the titanium-industry history at home and abroad, setbacks have been closely related to the economic and industrial difficulties in the aircraft and other industries. Recent rapid development of China's titanium industry is due primarily to the concerted efforts of all the people involved to exploit the titanium market. The key for successful development of the titanium industry is to find ways to expand fields where titanium can be applied.

Another reason why titanium applications must be broadened is that the service life of titanium equipment is semipermanent or permanent. In other words, success in titanium application in one field means future applications in that field are nearly nonexistent, and new fields must be found. To find new applications of titanium in plants that have not used it before, titanium alloys resistant to a wider variety of chemicals must be developed. Several successful cases have already been reported.

From the long-term viewpoint, China's titanium for aircraft applications will increase, but this will require further intensive research and development of new alloys and production techniques. Titanium will also enjoy greater demands from the aerospace and weaponry industries. Once China's titanium industry has attained a high technical level, it will follow the path of internationalization.

Improvement of Productivity and Quality of Titanium Sponge

The production scale of a titanium sponge plant in China using the Mg reduction process is 1,000 tons at present, which is extremely small. Plants abroad usually produce more than 5,000 tons. If production is increased to 10,000 tons, a 10- to 15-percent cost reduction is possible. Large-scale titanium sponge plants must be built in China in the near future.

In the Soviet Union and Japan, the combined process of reduction and distillation is extensively used. Use of this process can reduce fuel consumption by 15 to 30 percent and allows titanium sponge hardness to decrease below BHN80. At present a 2-ton batch-type furnace is being planned in China. When it is completed, energy consumption can be reduced by 25 percent as compared with the present rate and costs will drop by 16 percent. This plan should be realized as soon as possible.

Technical Transfer to Titanium Melting Plants

A great number of studies have been performed on commercialization of titanium, and significant milestones have been reached, but the following points still require urgent attention:

• Upsizing of melting furnaces

• Upsizing of forging equipment

• Operating titanium strip and welded tube lines immediately

Large-size plate rolling machines are also required.

Cost Reduction

In the course of development, titanium has been called the third metal, but this remains only a prophecy. From the 1981 statistics, total titanium sales stand 15th among metal sales. The titanium industry must speed up cost reductions in all processes. Planned long-term and short-term measures to reduce costs are as follows:

Long-Term Measures. Simple and efficient production processes must be developed. Electrolysis has been investigated for many years, but so far it has not

been successful; nevertheless, it remains a promising technique. Needless to say, it is important to use highly efficient production equipment, but the demand for titanium is still too small to proceed to mass production. There are many difficult problems awaiting solutions, but continued efforts are the only route to success.

Short-Term Measures. The production capacity of titanium sponge plants must be increased. Perfect Mg and Cl_2 cycling must be realized to increase productivity per furnace, and a combination process of reduction and segregation should be further refined. In the process after titanium sponge, complete titanium scrap recycling production lines should be established, final product yield improved by 6 to 8 percent, low-cost castings developed, and titanium equipment fabrication costs cut. For cost reduction, it will be necessary to develop a near-net-shape production technique, but this will require close cooperation from the scientific and industrial sectors.

Promoting Close Connection Between the Research and Production Fields

China's scientific research level has been improved as its titanium industry has developed. Close cooperation between the two sectors is a prerequisite to further development. Standards have improved considerably, but still more improvement is needed.

A large number of researchers are involved with titanium, in the fields of scientific research, production, design, and applications. Unification of research and production will become an especially important subject.

CONCLUSION

China's titanium industry is small but supported by a wide variety of domestic demands. Therefore, a great many people participate in basic and application-oriented titanium research. This was proved by a wide variety of lecture themes and interesting studies. The author was delighted to have had this opportunity to become more familiar with the current status of titanium research in China, a nation that is sometimes said to be near Japan in terms of distance but rather far in terms of cultural and personal relationships. Opportunities to get to know one another better through conferences like this one contribute greatly to the development of the titanium industries of both China and Japan, as well as strengthening the cultural ties and friendship between our two countries.

In November 1988, an international conference on metals, including titanium, will be held in Changsha, Hunan, under the joint auspices of China's Nonferrous Metal Institute and the Japan Mining Association, Japan Metal Academy, and American Society of Metals. This is an indication that internationalization of China's titanium industry is steadily progressing.

ACKNOWLEDGMENT

To discuss the Sixth Chinese Titanium Scientific Conference, the author primarily referred to the lecture of Mr. Li Quingyuan, chairman of the conference. I believe his lecture serves as an important guide for development of China's titanium industry.

Hidetake Kusamichi, who received both his B.S. and Doctor of Science degrees from Kyoto University, joined the staff of Kobe Steel, Ltd. in 1949. In 1963 he was promoted to chief researcher of the No. 5 Laboratory of the Central Research Laboratory. In 1977 he accepted the position of general manager, Titanium Metals Division. Dr. Kusamichi assumed his current position of adviser in 1984. The following year he also became an adviser for the China National Nonferrous Metal Industry Corporation. In addition to his two advisory positions, Dr. Kusamichi is chairman of both the Demand Development Council of the Japan Titanium Society and the Titanium Material Society of the Iron and Steel Institute of Japan. He has received numerous awards over the years, including the Distinguished Special Technical Service Medal from the Japan Titanium Society (1982).

Appendix

LIST OF TOPICS AND SPEAKERS

Topic	Speaker
Status and Prospects for China's Titanium Industry	Li Quingyuan* (Baoji Institute for Nonferrous Metal Research)
Titanium Applications in China	Gan Shujian* (Beijing Titanium Research and Development Center)
Effects of Microstructure and Texture on Fatigue Characteristics of Titanium Alloys	G. Luetjering* (West Germany)
Fracture Toughness of $\alpha + \beta$ Titanium Alloy	Lai Zuhan* (Shenang, Dongbei Technical Academy)
Anodizing and Alternate Immersion Corrosion Phenomena of Titanium and Titanium Alloys	P. Lacombe* (France)
Heat Stability of High-Temperature Titanium Alloy	Wan Xiaojing* (Shanghai Institute of Technology)
Melting and Mechanical Working of Titanium and Titanium Alloys	Hidetake Kusamichi* (Japan)
Titanium and Titanium Alloy Applications in Aircraft Industry	Yan Minggao* (Beijing Aerocraft Material Lab)
Structure Comparison of Titanium Ingots Produced by VAR and VADER (Possibility of using ingots directly for forging billets)	Xu Jialong* (Shanghai Iron and Steel Lab)
Fatigue of Titanium Alloys	J.A. Hall* (U.S.A.)
Strain Martensite Transformation of 10V-2Fe-3Al Titanium Alloy	Wang Shihong (Beijing Aerospace Lab)
Working & Heat Treatment of Titanium Alloys for Aeronautic Systems	R. Tricot* (France)
High-Speed Deformation and Heat/Toughness/Plasticity Instability of Titanium Alloys	Wang Lili (Hofei, China's Scientific and Technology University)
Hydrogen Embrittlement of 6Al-4V Titanium Alloy	Xiao Hangzhong (Shenyang, China's Scientific Academy, Metal Lab)
Fracture Toughness & Microstructure of 10V-2Fe-3Al Titanium Alloy	Wang Quanyou (Beijing Aerocraft Material Lab)
Phase Transformation of β-III Titanium Alloy	Zhang Qihai (Beijing, Nonferrous Metal General Lab)
Atmospheric Diffusion Welding Technique of Microporous Titanium Materials and Applications	Liu Shiwei (Kuangchou Nonferrous Metal Research)
Titanium Urea Production Equipment	Huang Jiahu (China's Machinery Ind. Committee, Chem. Fert. Machinery Lab)
Effect of Heat Treatment on Vibration Absorption Capabilities of Titanium Alloys	Han Chuanxi (Baoji Institute for Rare Metal Research)
Vital Test of Microporous Titanium Materials	Zou Hongen (4th Military Medical Univ.)
Research on Dynamic Recrystallization Phenomena of TC11 Titanium Alloy	Yang Quanmin (Hsian, Xibci Technical Institute)

*Guest speaker

FIFTH GENERATION COMPUTER SYSTEM (FGCS)

H. Yoshihara

Japan's Fifth Generation Computer System (FGCS) is an advanced information processing computer with an intelligent inference capability designed to address the expected social and economic problems of the 1990s. The Institute for New Generation Computer Technology (ICOT), established to develop a prototype of the FGCS, and its key personnel are described together with the details of the 10-year development plan. The progress to date and the future research plans for the two primary subsystems, the Problem Solving and Inference Unit and the Knowledge Base System, are reviewed.

WHAT IS FGCS?

The goal of Japan's Fifth Generation Computer System (FGCS) project is to develop a versatile knowledge information processing system to address the economic and social problems expected in the 1990s. Clearly, an important motivation is the promotion of the competitive position of the mainline industries. Special attention, however, is also to be paid to the low productivity areas such as agriculture and fishing; to the goods distribution system; to the conservation of energy and resources; and to the improvement of the quality of life of the people, particularly for the rapidly growing senior citizen group.

Japan, as a leading economic power, feels obligated to promote the well-being of the Third World nations by addressing the above problems through the FGCS. Moreover, success in the FGCS project will remove the undeserved stigma that Japanese talents do not extend to software.

FGCS will also address the problem of the language barrier currently hindering international communications as well as the projected software "programmer crisis" wherein some extrapolations of the requirements exceed the population itself.

Though computers are a relatively recent phenomenon, their development to date has been categorized into four generations, a new generation commencing with the introduction of a significant new hardware device. Thus, after the first generation characterized by the use of vacuum tubes, in succession came the second generation with the introduction of the transistor, the third with the integrated circuit, and the fourth with the very large scale integration (VLSI). The FGCS, though it does not necessarily incorporate a new breakthrough device, has been categorized in the fifth generation since it differs significantly from current "number crunching" supercomputers. It is a highly advanced knowledge information processing computer system with unprecedented inference capabilities.

In short, the FGCS is to be a real-time knowledge information processing system with intelligent inference (artificial intelligence) capabilities to solve the problems in the decade of the 1990s.

BACKGROUND OF THE FGCS

As will be seen shortly, FGCS's goals are ambitious. They were, however, established after a thorough study carried out over a period of 3 years, fiscal years 1979 to 1981. (The fiscal year commences on 1 April in Japan.) The first 2 years of the preliminary study were supported by the Japan Information Processing Development Center (JIPDEC), a nonprofit private organization, under the leadership of Professor T. Moto-oka, Electrical Engineering Department of the University of Tokyo. Professor Moto-oka played a key role in the subsequent studies as well as in the FGCS itself, but unfortunately passed away abruptly in late 1985, a great loss to the FGCS.

The third year of the study phase was taken over by the Ministry of International Trade and Industry (MITI) and carried out in three parts. The first part was headed by Mr. H. Karatsu of the Matsushita Electric Industrial Company and addressed the question of the social/economic environment to be expected in the 1990s and the concomitant information processing requirements. Understandably, great importance was placed on this phase of the planning. The second task, headed by Professor H. Aiso, Electrical Engineering Department of Keio University, covered the area of computer (hardware) technology. The third task was headed by Mr.

K. Fuchi, Electrotechnical Laboratory (MITI-Tsukuba), who researched the potential computer software issues. Professor Moto-oka, Mr. Karatsu, Professor Aiso, and Mr. Fuchi were key personnel in the FGCS project.

As a result of the above studies, MITI, in April 1982, established the Institute for New Generation Computer Technology (ICOT) to undertake the development of a prototype of the FGCS. This project was planned for a 10-year period in three stages. The initial stage (3 years) was a basic research phase where optimal approaches were independently sought for each of the planned subsystems. In the intermediate stage (4 years), combinations of the more promising subsystem concepts would be optimized for overall system performance. In the final stage (3 years) a prototype of the FGCS would be designed, constructed, and demonstrated. Fiscal year 1988 is the third year of the intermediate stage.

In the next sections, the organization of ICOT is given followed by a brief description of the principal subsystems of the FGCS and their present status.

ORGANIZATION OF FGCS RESEARCH AND DEVELOPMENT

To implement the FGCS project, ICOT planned a three-pronged approach. The first and most important is the in-house research to be carried out within the ICOT Research Center directed by Mr. Fuchi. The second is the advisory functions carried out by six working groups of the Project Promotion Committee chaired until 1985 by Professor Moto-oka. Members of the

working groups are recruited from universities and industry. Finally, ICOT is depending upon an important input through an international exchange of research information. ICOT considers the latter important, and regularly sponsors international symposia and encourages international exchange of research personnel.

The ICOT Research Center, where the primary FGCS research and development (R&D) effort is to be carried out, is housed in the Tokyo high-rise Mita Kokusai Building, appropriately on the "lofty" 21st floor. During the initial stage (completed in fiscal year 1984), the staff was composed of about 70 people of which 40 comprised the permanent staff while 30 were appointed for the 3-year duration of the initial stage. The latter temporary group was largely recruited from nearby computer and electrotechnical companies having an interest in information processing or artificial intelligence. They would be replaced by succeeding groups for each new stage with a brief overlap of the groups between stages. An intent of this personnel rotation was to establish a pool of talent skilled in the field of information processing. Thus, after the appointment, the researchers could return to their parent companies and use their ICOT experience to pursue FGCS-related research. Interestingly, there was an upper bound on the age of 35 years for the temporary appointments.

The staff of the ICOT Research Center as of 1988 was about 85 people, anticipated to grow to 100 for the final stage.

GENERAL FEATURES OF THE FGCS

FGCS is a knowledge information processing system and as such must be significantly more sophisticated than the more familiar number-processing computers. That is, the computer software and hardware must deal with sets of (logic) rules and relations rather than sets of numbers. As planned by ICOT, the heart of FGCS is to be composed of the Problem Solving and Inference Unit ("central processing unit"), the Knowledge Base System (memory unit), and the Intelligent Interface Unit (input/output unit) (see Figure 1).

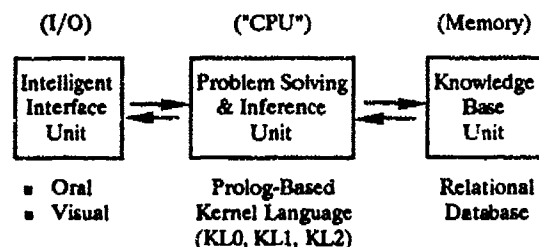| (I/O)	("CPU")	(Memory)
Intelligent Interface Unit	Problem Solving & Inference Unit	Knowledge Base Unit
■ Oral ■ Visual	Prolog-Based Kernel Language (KL0, KL1, KL2)	Relational Database

Figure 1. Schematic of FGCS.

The Problem Solving and Inference Unit evolves the answer using logical reasoning (rules of first order predicate logic) on the information retrieved from memory. The software for this unit employs inference techniques including deductive or inductive processes and informed guessing when the knowledge available is inadequate.

Examples of sets of rules that must be manipulated range from the simpler rules of algebra and calculus to the more difficult rules pertaining to vocal and visual pattern recognition.

The Knowledge Base System provides rapid storage and retrieval of information. To accommodate the unprecedented amount of information that will be required, a relational database system will be employed. That is, information will be stored, not only in the form of a baseline set of information but in the form evolvable by a set of rules (predicate logic) operating on the baseline information.

The Intelligent Interface Unit provides the input/output (I/O) for the FGCS. To insure computer access at all user levels, FGCS planners have provided for the I/O to be both vocal (for example, in any language or with any accent) or visual (either written or by pictures). Such generality of the I/O will be a formidable challenge.

A fourth task planned by ICOT was the design of the Intelligent Programming Unit for the FGCS, which would take over the burden of application programming from the error-prone human.

All four devices, the Problem Solving and Inference Unit, Knowledge Base System, the Intelligent Interface Unit, and the Intelligent Programming Unit, have clear and direct application to artificial intelligence (expert systems, robotics, etc.).

In the following section the present status of the Problem Solving and Inference Unit and the Knowledge Base System is given. Progress on the Intelligent Interface Unit and the Intelligent Programming Unit is understandably far less advanced and thus will not be reported herein.

CURRENT STATUS OF FGCS

Problem Solving and Inference Unit

A key accomplishment to date is the completion of a sequential logic programming language, KL0. (Here KL stems from the name Kernel Language adopted by FGCS, with 0 denoting a preliminary sequential version.) The point of departure for KL0 was the existing logic programming code Prolog rather than the more established symbol-manipulating List Processing (LISP) language. This resulted in some initial controversy from the artificial intelligence community who primarily used LISP. Selection of Prolog, aside from its descriptive power, was due to its having the same base, namely predicate logic, as the relational database system preferred for the Knowledge Base System.

To gain programming experience with the KL0 language, the Personal Sequential Inference (PSI) machine was developed and demonstrated. It was built by the Mitsubishi Electrical Company and directly executed KL0 as its machine language via a compiler embedded in the computer operating system. Some features of the PSI machine are as follows:

Central Processor:	Microprogrammed sequential processor
Memory:	16M 40-bit words (main memory) 2 x 4K 40-bit words (cache)
I/O:	17-inch bit map display with mouse Two 38-MB disks 180 character per second serial printer
Local Area Network (LAN):	Ethernet 10 MB/s
Performance:	200 ns clock time 30K LIPS (logical inferences per second)

PSI is thus comparable to the DEC 10 Prolog Machine (DEC 2060) in speed with a memory 64 times larger. Currently there are 60 operational PSI machines serving as work stations for the researchers to develop and improve the KL0 language.

Because of the programming difficulties experienced with KL0, a higher order, more user-friendly language, the Extended Self-Contained Prolog (ESP), was also developed.

More recently, an improved PSI machine, PSI II, was developed that incorporated an improved compiling technique using the Warren Abstraction Machine code to bridge between KL0 and machine languages. Here emphasis was placed in miniaturizing PSI II to make it more appropriate for a work station.

The above progress was largely accomplished during the initial stage, in which the emphasis was on gaining experience with logic programming, the foundation for FGCS. The focus of the intermediate stage is on increasing the speed of the knowledge information processing by employing a concurrent or parallel approach. Currently a concurrent logic programming language, KL1, together with bridging languages, both between KL1 and the machine and between KL1 and the user, are in the process of development.

In concert with the development of the concurrent programming languages, a Parallel Inference Machine (PIM) is being designed. The initial version will have 100 parallel processing elements to be increased to 1,000 in the final prototype.

As an interim concurrent machine, 64 reconfigured PSI II machines will be connected in parallel and used to gain programming experience with KL1, to evolve improvements to KL1, and to develop higher order, more user-friendly languages comparable to ESP. Because of the wide spectrum of users, it is not unlikely that a number of tailored user languages will evolve.

The concurrent language developed for use in the final prototype will be designated as KL2.

Knowledge Base System

The Knowledge Base System is the memory system that furnishes information to the Problem Solving and Inference Unit. The database format selected by FGCS was the relational database, in which information is defined in the form of rules. During the initial stage, Delta, a prototype of the Knowledge Base System, was completed and demonstrated. It was composed of two subsystems, the Supervisory and Processing (RSP) Subsystem built by the Toshiba Company and the Hierarchical Memory (HM) Subsystem built by the Hitachi Company.

The RSP Subsystem is composed of a control processor that compiles (translates) the incoming relational algebra commands into an executable form to direct the four Relational Database Engines and the Hierarchical Memory during the query processing. The Relational Database Engines are dedicated hardware units for relational operations. The Hierarchical

Memory is composed of a high-performance semiconductor memory unit with a capacity of 128 MB and eight disks each with 2.5 GB capacity. The latter disks contain the database, whereas the memory unit serves as a buffer or a cache.

The 60 PSI work stations are connected to the above Delta Knowledge Base System by a Local Area Network, an Ethernet with a transmission rate of 10 MB/s.

The above effort on the Knowledge Base System was completed in the initial stage. Future efforts in the intermediate and final stages will focus on establishing a parallel processing architecture for the Knowledge Base machine and building a prototype. Through a learning process, the characteristics of the parallel prototype will be determined, from which improvements are to be evolved. A distributed network of the above parallel Knowledge Base System will be developed for the final prototype.

The tasks will be carried out within the organizational structure shown in Figure 2.

- Kernel Language (KL2)
- Intelligent Programming Unit

- Intelligent Interface

- Knowledge Base Software & Hardware

- Parallel Inference Machine
- Kernel Language (KL1)

- User Languages
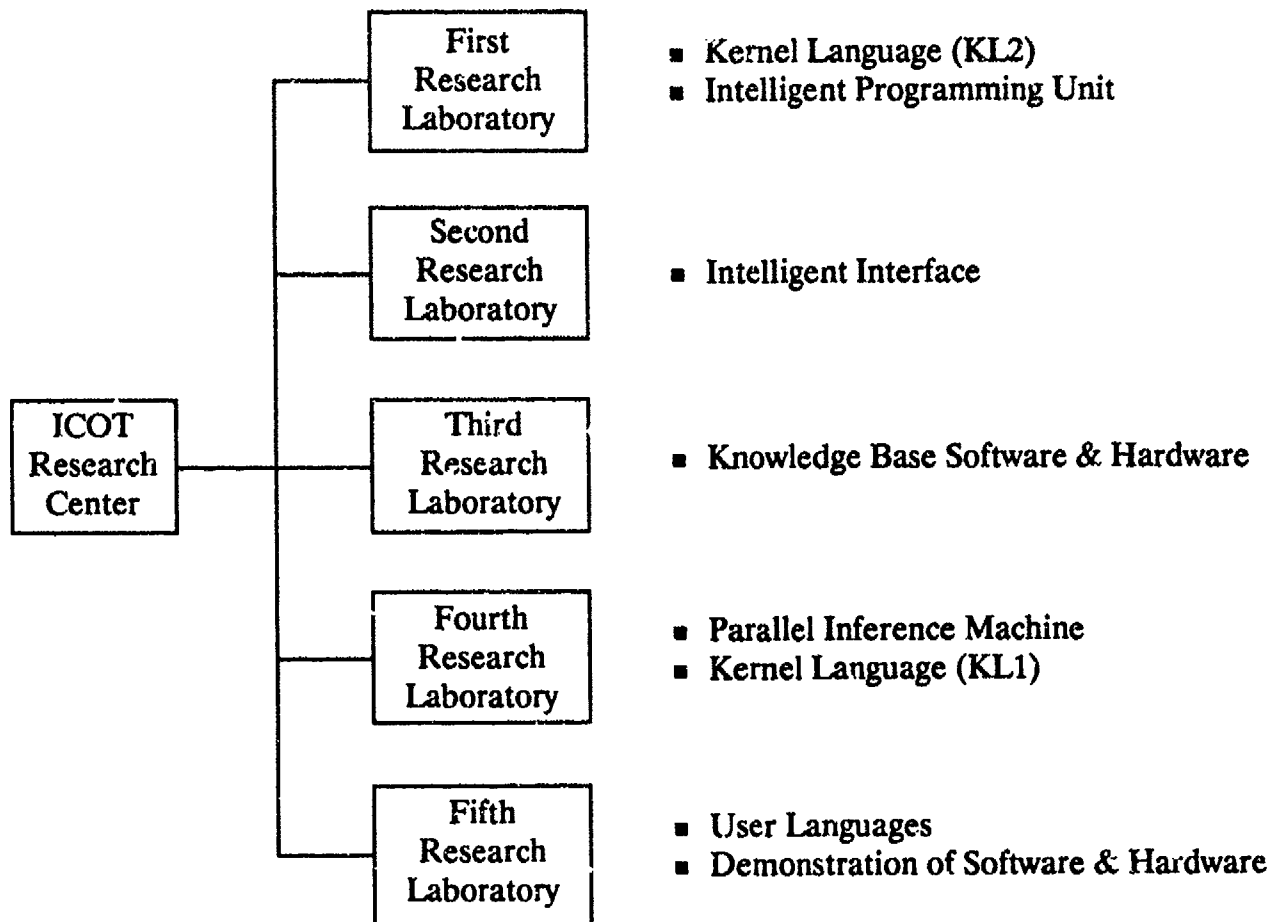- Demonstration of Software & Hardware

Figure 2. Organization of the ICOT Research Center.

SUMMARY REMARKS

The Fifth Generation Computer System Project being carried out by ICOT is an ambitious project. The planning for it has been thorough, and it has been managed by a farseeing and yet pragmatic management. Most importantly, ICOT has had the support of the Government, receiving funding in a timely and continuous fashion. (In May 1988 MITI approved a sum of ¥30 billion for the final 3 years in which a prototype of the FGCS is to be completed.)

R&D for the FGCS is intended by ICOT to be open to the international community. The present FGCS summary was in large part obtained from ICOT journals (translated into English), which were received 1 week after they were requested. ICOT believes that an international exchange of research information is essential. Thus, for example, cooperative efforts have been arranged with various nations, most recent of which is with the United States National Science Foundation. Accordingly, ICOT will accept up to three U.S. researchers per year, who will be assigned directly to an ICOT laboratory, for a tour of 6 to 12 months. (The first was Dr. Evan Tick, a graduate of Stanford University, who also kindly reviewed this summary.)

How well the FGCS project achieves its final objective may be moot. Much more significant is the extensive industrial and academic R&D motivated by the existence of the FGCS project that has helped project Japan to one of the leading roles in information processing and artificial intelligence for the future. FGCS must be considered a cost-effective investment for the decade of the 1990s.

Finally, for those desiring further details of the FGCS, either of a general nature or specific details of the hardware or software, copies of the ICOT journal or a list of available technical reports may be obtained from:

Institute for New Generation
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Japan

Hideo Yoshihara arrived in Tokyo in April 1988 for a 2-year assignment as a liaison scientist for the Office of Naval Research. His assignment is to follow the progress of advanced supercomputers and to review and assess the viscous flow simulation research in the Far East. Dr. Yoshihara formerly was with the Boeing Company, where he was Engineering Manager for Applied Computational Aerodynamics. He was also an affiliate professor in the Department of Aeronautics and Astronautics of the University of Washington, an AIAA Fellow, and a former member of the Fluid Dynamics Panel of AGARD/NATO.

MAGNETIC SHIELDING WITH A SHAKING FIELD

Ichiro Sasada and Earl Callen

Magnetic shields are used to reduce external magnetic noise. The region to be shielded is surrounded by a high permeability case. It has long been known that shielding can be increased by magnetically "shaking" the case in a high-frequency, large-amplitude magnetic field. In previous studies, with two layers of Mumetal, shaking improved shielding by a factor of 8 or so. The key to effective shielding is the selection of the right shield material. Metglas 2705M is an amorphous soft magnet with small magnetostriction and highly rectangular hysteresis loop. Shaking increases shielding by a factor of 42 with two layers of Metglas 2705M and by a factor of 70 with a single layer.

INTRODUCTION

Magnetic shielding using shaking fields was described in 1915. To understand what underlies the idea let us begin with a description of the B-H curve of a ferromagnetic material and its major and minor loops. Consider the induction when a ferromagnetic material is exposed to a slowly cycling external field. After the ferromagnet is first magnetized, as the external field cycles back and forth the induction B and the magnetization M traverse a hysteresis loop, as shown in Figure 1. On the steep ascending and descending arms of the loop the mechanism of magnetic response is domain wall motion; domains aligned with the driving field grow at the expense of antialigned domains (from the previous half cycle). But as the magnetization approaches saturation in the (more or less) single domain state beyond the points of inflection, the mechanism of magnetization is moment rotation. Within each small crystallite there is a set of easy axes. The magnetic energy is least when the moment of the crystallite lies along one of these axes. In iron the < 100 > are easy and in nickel the < 111 > are easy. In a polycrystal sample the crystal axes are randomly oriented, or only partially oriented, and so at external field strengths less than the anisotropy field the set of crystallite moments lie along easy axes in the hemisphere toward the field direction. As the field is increased the moments in the crystallites are rotated from the easy axes toward the field. The situation is actually a bit more complicated, with both irreversible and reversible processes. For a more thorough description see a text on magnetics (Ref 1).

Domain wall motion, beyond that induced by the very smallest fields, is intrinsically irreversible. A variety of barriers-- impurities, voids, internal strains, spike domains, dislocations, grain boundaries-- impede the movement of domain walls. Schematically, one can imagine the energy as a function of wall position as a series of bumps of irregular spacing, width, and height. Pushing the domain wall past these bumps is an irreversible process; energy is dissipated. The area of the hysteresis loop represents the energy transferred from the external field to the magnetic system and ultimately to the lattice, appearing as heat. Again we refer the reader to a standard reference (Ref 1).
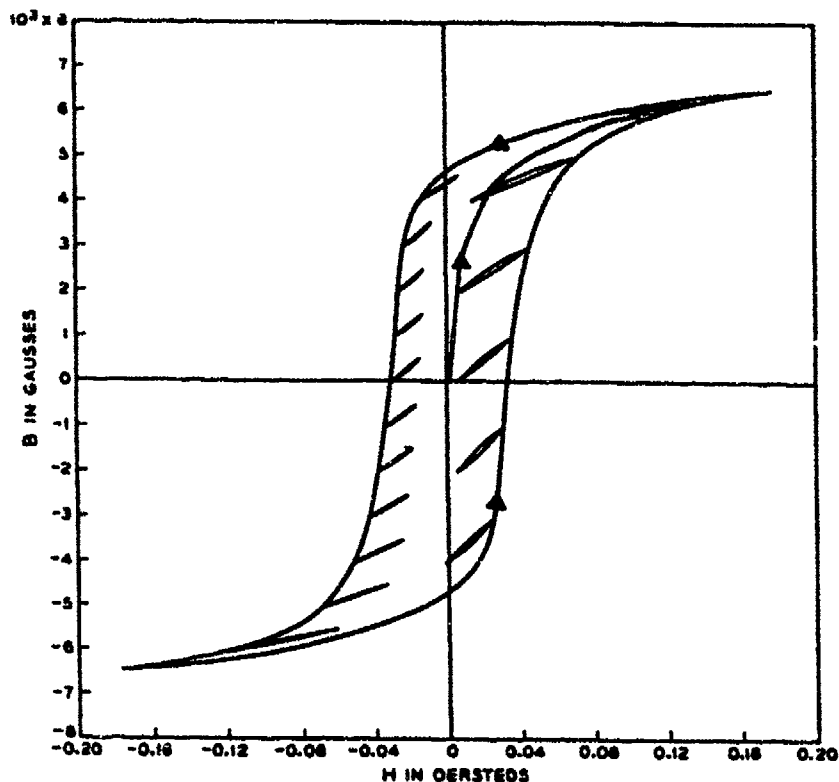
Figure 1. Major and minor hysteresis loops for 4-79 Permalloy. The arrows show the path around the major loop, starting from the demagnetized state.

Now imagine there to be both a biasing dc and a parallel, oscillatory external field. With the bias field the magnetization can be set at any point on the hysteresis loop, and with the ac field the magnetization can be jiggled, and the domain walls wiggled back and forth around their equilibrium positions. We wish to understand how the magnetization responds to the oscillatory field (see Figure 2). The oscillatory field is imagined to be turned on after H_b is set and thereafter the field is:

$$H(t) = H_b + H' \sin \omega t \qquad t > 0$$

At $t = 0$ the field and induction are at $(H_b, B^{(0)})$. A quarter cycle later the field is maximum, $H^{(1)} = H_b + H'$, and the induction is $B^{(1)}$. But in the next quarter cycle, as H reverts to H_b, B does not return to $B^{(0)}$; it reduces much less, to $B^{(2)}$. A quarter cycle later, $H = H_b - H'$, and B retreats only to $B^{(3)}$. After a full cycle of the oscillatory field, when H is again H_b, $B^{(4)}$ is only slightly less than $B^{(2)}$, and thereafter around the loop. These are the minor loops. The construction shows that they always lie inside the major loop. Their incremental permeability,

$$\mu_\Delta = \frac{\Delta B}{\Delta H} = \frac{\Delta B}{2H'}$$

is a slowly varying function of H', the amplitude of the oscillation, *but is significantly less than the slope of the magnetization curve.* As

the amplitude H' is increased, changes occur in the location and shape of the minor loop. For (vanishingly) small oscillatory field amplitude, and hence small domain wall displacement in the local valleys, the motion is reversible. But as the minor loop increases in amplitude, domain walls sweep past more and more impediments, energy is lost, and the small loops open up. By convention B_b, the biasing induction, is at the center of the minor loop (as is H_b, of course). Note that for fixed H_b, B_b depends upon H'. For a fixed starting point on the hysteresis curve, as H' is increased the loss increases but also the incremental permeability increases, and the point (H_b, B_b) rises vertically (and irreversibly) within the major loop. The reversible permeability μ_r is the limiting incremental permeability at H' = 0. μ_r is *not* the slope of the major hysteresis loop at that point but is much less (except in the saturated extremes of the hysteresis loop, where the loop is reversible).

SHIELDING

The purpose of magnetic shielding is, of course, to reduce or eliminate some constant or time-varying external magnetic field in a region. This is accomplished by enclosing the region. Reference 2 is a review of magnetic shielding. The ultimate shield is a superconductor. Magnetic fields of strength less than H_{cl}, the lower critical field, cannot penetrate the superconductor. (In type I materials the upper and lower critical fields coalesce with the critical field H_c.) A bladder of superconductor expanded while in the superconducting state repels and excludes magnetic field. If one needs to exclude only time-varying fields but can tolerate constant, trapped flux, an expanded bladder is not necessary, only a superconducting shield. In either

event the superconductor must be kept cold, and shielding is effective only for disturbance fields less than the lower critical field. The superconducting oxides will someday serve at liquid nitrogen temperature (and at room temperature), but their lower critical fields are for many purposes now too low; flux lines sneak through. An exception is space applications. There the ambient temperature is 3 K, so with no effort the oxides are superconducting (as are many conventional superconductors). And if the field to be shielded is the Earth's magnetic field, it is below H_{cl}.
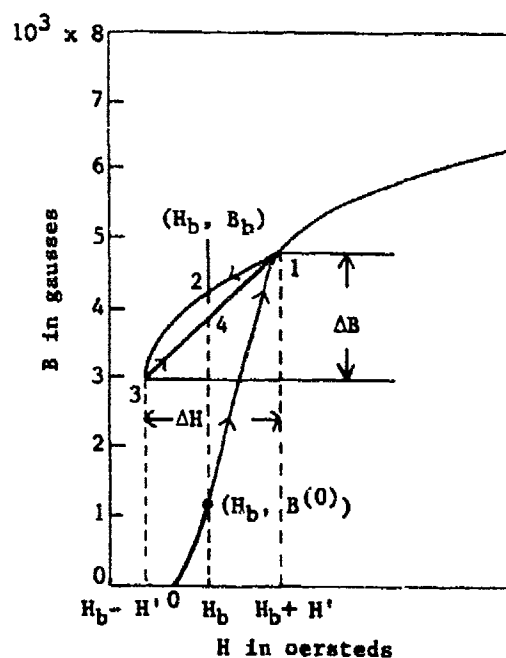
Figure 2. A minor loop. After traversing the major loop an oscillatory field of small amplitude is applied. The response is irreversible; as H is increased to $H_b + H'$, B increases from $B^{(0)}$ to $B^{(0)} + \Delta B$. Thereafter the response is cyclic, traversing the minor loop. The incremental permeability is the slope of the minor loop and the bias point is at the center of the minor loop. Its ordinate depends upon the oscillatory amplitude H'.

But for most earthbound applications the conventional method of shielding is by using a combination of techniques (Ref 2). A metal shell, aluminum or copper, eliminates higher frequency disturbance fields. Bucking coils create fields opposing background fields. The shielded space is enclosed in one or more layers of a ferromagnetic material, one with reasonably high permeability but not-inordinate cost, such as Mumetal. And around these sheets are looped a few turns of shaking coils, which may be coincident with the bucking coils.

We shall soon return to shaking, but first let us look at the principle of magnetic shielding. A calculation is helpful. In the box we examine the example of a spherical shell of magnetic material. It is placed in a (previously) uniform magnetic field H_{ext}. The shielding factor is defined as the ratio of the external field strength to the field strength inside the shield:

$$S = \frac{H_{ext}}{H_i}$$

The problem is to calculate S.

Shielding by a Spherical Shell

Imagine a spherical shell of magnetic material of permeability μ. The inner and outer radii of the shell are a_1 and a_2. In spherical coordinates, with the z-axis along the applied field, Laplace's equation separates. The magnetostatic potential and the fields are independent of the angle around the z-axis, and so in the three regions (outside, in the shell, inside) the potentials can be written generally as

$$U = \sum_{\ell=0}^{\infty} A_\ell \, r^\ell \, P_\ell(\cos\theta)$$

$$+ \sum_{\ell=0}^{\infty} \frac{C_\ell \, P_\ell(\cos\theta)}{r^{\ell+1}}$$

and the magnetic field strengths as

$$H = -\nabla U$$

Since the magnetic shell has $\ell=0$ symmetry and the applied field is an $\ell=1$ harmonic, the response can be at most of $\ell=1$ character. Inside the shell the potential must be finite at the origin; there can be no inverse powers of r. In this region the only surviving coefficient is A_1^i (and the inconsequential A_0^i, which does not contribute to the field strength). Outside the shell the field must be well behaved at infinity, which would eliminate A_2 and above, but on

symmetry grounds we have already dropped these divergent terms in the series. In the shell layer and outside, C_0 are the coefficients of the spherically symmetric $1/r$ potential. Since there are no magnetic poles, these coefficients must be zero. (These terms correspond to the potential arising from the net charge in an electrostatics problem.) The only terms remaining in the series are:

$$H^i = -A_1^i \cos\theta \, \hat{i}_r + A_1^i \sin\theta \, \hat{i}_\theta$$

$$H^s = \left[-A_1^s + \frac{2C_1^s}{r^3} \right] \cos\theta \, \hat{i}_r$$

$$+ \left[A_1^s + \frac{C_1^s}{r^3} \right] \sin\theta \, \hat{i}_\theta$$

$$H^o = \left[-A_1^o + \frac{2C_1^o}{r^3} \right] \cos\theta \, \hat{i}_r$$

$$+ \left[A_1^o + \frac{C_1^o}{r^3} \right] \sin\theta \, \hat{i}_\theta$$

Note that inside the shell the field is strictly vertical (compare this to electrostatics). At large distances outside the shell the field must revert to the imposed field:

$$-A_1{}^o = H_{ext}$$

We now match boundary conditions. Tangential H (i.e., H_ϕ) and normal B (i.e., B_r) must be continuous. At boundary a_1:

$$A_1{}^i = A_1{}^s + C_1{}^s/a_1{}^3$$

$$-\mu_o A_1{}^i = -\mu A_1{}^s + 2 \mu C_1{}^s/a_1{}^3$$

and at a_2:

$$-H_{ext} + \frac{C_1{}^o}{a_2{}^3} = A_1{}^s + \frac{C_1{}^s}{a_2{}^3}$$

$$\mu_o H_{ext} + \frac{2\mu_o C_1{}^o}{a_2{}^3} = -\mu A_1{}^s + \frac{2\mu C_1{}^s}{a_2{}^3}$$

It is convenient to define the relative permeability

$$k_m = \mu/\mu_o$$

and a ratio of radii

$$\rho = a_2/a_1$$

Both k_m and ρ are 1 or greater.

Solving, one finds the shielding factor to be

$$S = \frac{1}{9}\left[5 + 2 k_m + \frac{2}{k_m}\right.$$

$$\left. + \frac{2}{\rho^3}\left(2 - k_m - \frac{1}{k_m}\right)\right]$$

It is satisfying to see how the shielding factor behaves in the limits. When $k_m = 1$ the shell is magnetically indistinguishable from free space and S = 1. When $\rho = 1$ the shell is of zero thickness and S = 1. As k_m becomes infinite, S approaches infinity and the external field is completely shielded from the interior.

Usually the shell thickness t is small compared to its radius a. We can expand to first order in t as

$$\frac{1}{\rho^3} \approx 1 - \frac{3t}{a}$$

The shielding factor then reduces to

$$S \approx 1 + \frac{2}{3} \frac{t}{a}(k_m + \frac{1}{k_m} - 2)$$

In the normal event $k_m >> 1$. The shielding factor is then simply

$$S \approx 1 + G k_m t/a$$

G is a shape-dependent factor of the order of 1. For spheres G = 2/3. For example, for $k_m = 10^4$ (e.g., Mumetal) and t/a = 10^{-2}, S = 67.

We shall wish to compare the effectiveness of various magnetic materials. Since their shielding factors were obtained under different experimental conditions, with different geometries, this is best done by working backwards through the above equation. That is, one measures the shielding factor S and, knowing the appropriate geometrical factor G, calculates the effective relative permeability k_m. For an electromagnetic disturbance beamed normally at the side of an infinitely long square pipe of transverse edge length L (a = L in equation above), G = 0.7. For normal incidence on an infinite-length circular pipe of radius a, G = 0.5 (or more conveniently, in terms of the diameter 2a, G = 1).

MAGNETIC SHAKING

If price were no consideration one would make magnetic shields of a very high permeability material such as supermalloy. But is there a way to attain that high permeability with less expensive shields? In 1915, Steinhaus and Gumlich (Ref 3) first stated that the magnetic response to a low-frequency signal could be considerably enhanced by the simultaneous application of a large-amplitude, high-frequency magnetic field to the ferromagnetic shield. But apparently Steinhaus and Gumlich's work was not widely known, for in 1925 T. Spooner wrote (Ref 4):

> It is often assumed that when an alternating magnetizing force is superposed on a constant magnetizing force, the permeability of the magnetic material is increased and the hysteresis loss decreased due to the shaking-up action of the alternating current on the magnetic particles. It is shown that these effects are only apparent and that the true permeability and hysteresis remain approximately the same as under constant field conditions.

Spooner cites a concurrent Japanese publication that comes to the same conclusion (Ref 5). Spooner, who coined the name "shaking," goes on to show that in fact hysteresis loss is not suppressed but is increased; it is the sum of the major and minor loops traversed. Spooner is right about the hysteresis loss, but though he errs about permeability, we can understand his argument; it is just that of our Figure 2.

But suppose circumstances are those proposed by Steinhaus and Gumlich. Suppose the amplitude of the oscillatory field is as large as the coercive force, and one wishes to shield out a slower varying or dc field of smaller amplitude. This situation has not been analyzed mathematically in a satisfactory fashion, but there is a consensus on the hand-waving argument, which goes as follows. It is like sliding friction and static friction. The higher frequency field of large amplitude pumps energy into the system, driving the domain walls back and forth over barriers. This allows the system to be responsive to the slowly varying disturbance field. In a sense (but not as far as the loss is concerned) the large-amplitude, high-frequency field applied to the shield collapses the hysteresis loop seen by the disturbance field so that the effective permeability is the ideal permeability. That is what is observed and that is magnetic shaking. A design is illustrated in Figure 3 A few turns of shaking coils, connected to a relatively high frequency power source, are wrapped around the ferromagnetic sheeting. The coils are arranged so as to create a closed shaking flux path in the ferromagnetic shield. This both increases the shaking efficiency and reduces intrusion of the shaking field into the cavity. The shaking coils are also used to demagnetize the magnetic layers. Within the magnetic shield is the nonmagnetic metallic layer. This helps shield high-frequency components of the disturbing field as well as the shaking field itself, and for this a higher shaking frequency is better. At 1 kHz there is no penetration of the shaking field into the cavity.

Steinhaus and Gumlich's perception did become known, of course. Albach and Voss (Ref 6) reiterated it in 1957, and in 1967 Cohen (Ref 7) reported an investigation of the frequency dependence. He shook a ferromagnetic shield (by means of a coil) at 60 cps. The disturbance field was varied in frequency. There was little decrease in shielding factor up to about 40 hertz, then a gradual dropoff as the disturbance field frequency approached and exceeded the shaking frequency. Cohen (Ref 8) also described the design of a magnetically shielded room with shaking coils. The room was enclosed by a layer of 0.19-inch-thick aluminum sheeting. Outside the aluminum sheet were two layers of 4-79 Moly-Permalloy, each 0.06 inch thick. Over the effective frequency range shaking increased shielding by a factor of about 8.

Kelha, Peltonen, and Rantala (Ref 9) confirmed Cohen's (Ref 7) observations. At fixed shaking frequency shielding was a maximum at zero disturbing field frequency and dropped monotonically with increasing frequency. Kelha et al. found that the optimum shaking amplitude for maximum shielding shifts to a higher amplitude with higher shaking frequency. There is a broad maximum. The investigators found shaking to increase the permeability of Mumetal by a factor of 5. With two layers of Mumetal and shaking, the shielding factor was about 89. The cavity studied by Kelha et al. was of square cross section, edge $L = 200$ mm, with 2 mm of Mumetal. From the final equation in the box one finds an effective relative permeability $k_m = 12,570$. This is about the same as obtained by Cohen (Ref 7,8).
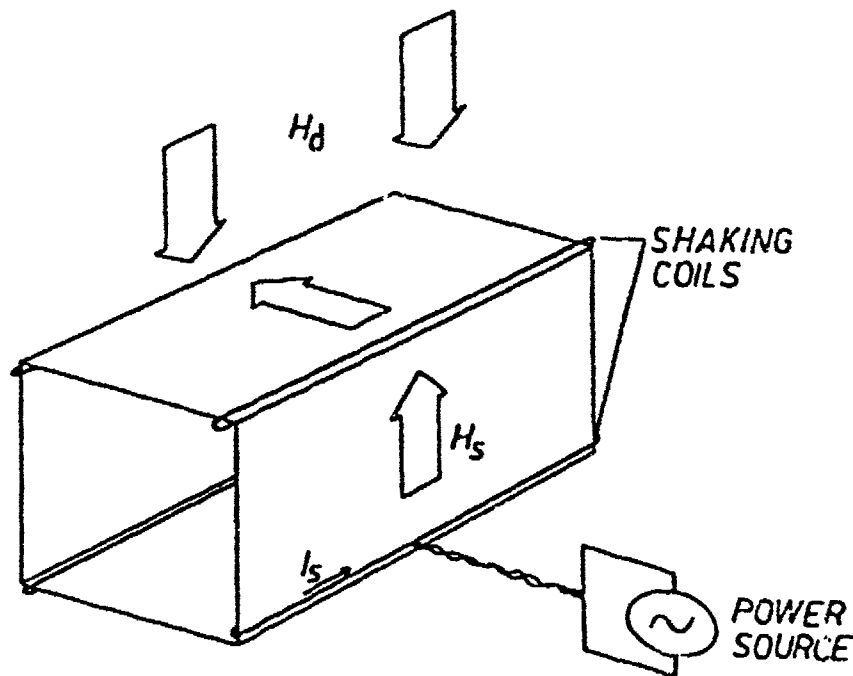

Figure 3. The rectangular geometry of Kelha et al. (Ref 9). Shielding is linear in t/a, ratio of thickness to transverse radius of the cavity, but is almost independent of shape. For spheres and for circular and square cross-section pipes of infinite length, the several shape factors G are all close to unity.

Sasada, Kubo, and Harada (Ref 10) of Kyushu University are now showing how to improve magnetic shielding dramatically. The key is the selection of the right material. Sasada et al. use Metglas 2705M amorphous ribbon. This is a soft magnetic material with small magnetostriction and a highly rectangular B-H loop with nearly vertical sides. The coercivity is small, about 0.5 A/m. The ribbon, about 22 μm thick, is attached over the outer surface of a cylindrical copper pipe whose diameter 2a = 65 mm. In some experiments Sasada and his students fix two layers of wide ribbon of the amorphous Metglas on the copper pipe; in later experiments only a single layer is used. A few loops of coil wire are turned toroidally (i.e., parallel to the longitudinal axis) through the pipe and its Metglas sheath and around. By means of a Helmholtz coil a low-amplitude, 10 hertz disturbing field is beamed transversely at the pipe. A dc component of the field from the Helmholtz coil cancels the ambient earth's field. Without shaking the shielding factor is 3.5. Shaking increases shielding by a factor of 42. This is eight times better than the earlier results discussed above. Sasada's shielding factor of 147 corresponds to an effective permeability for Metglas 2705M (substituting t = 2 x 22 μm, 2a = 65 mm), k_m = 2.1 x 10^5, about 16 times that of Mumetal.

In applications where the overriding consideration is maximum shielding, the designer may be willing to call for thicker and more expensive magnetic material. In other circumstances it will be important to do as well as possible with a single, thin magnetic layer. Sasada has also investigated how well he can do with a single layer of 22 μm thick Metglas 2705M ribbon. The demagnetization factor of the ribbon should be used to advantage. For the arrangement Sasada uses, the ribbon is wrapped helically around the copper pipe. Figure 4 shows the dependence of shielding factor on shaking field amplitude. With one layer the shielding factor is 125--almost as high as that obtained with two layers. The relative permeability is about 3.4 x 10^5. Note that at higher shaking field amplitude, shielding again decreases sharply.

Sasada and his students have also investigated how shielding depends on the ratio of frequencies, f_s/f_d, for fixed shaking and disturbing field amplitudes. In agreement with previous work they find that shielding rises monotonically with increasing f_s/f_d. They also find that at fixed ratio f_s/f_d, the lower the shaking frequency the higher the shielding.

Shaking seems to work by pumping energy into the magnetic system, thus loosening up the domain walls. With this in mind Sasada et al. have studied the relative shielding factor S/S_o (ratio of S with shaking to S without shaking) versus shaking flux density B/B_s (ratio of flux density to saturation flux density of the ferromagnet). Measurements conform to their expectation in that the enhancement attained by shaking is independent of shaking frequency: curves for f_s = 100 hertz and for f_s = 1 kHz are almost coincident. The curves all show a broad maximum at a flux density about half that of saturation.
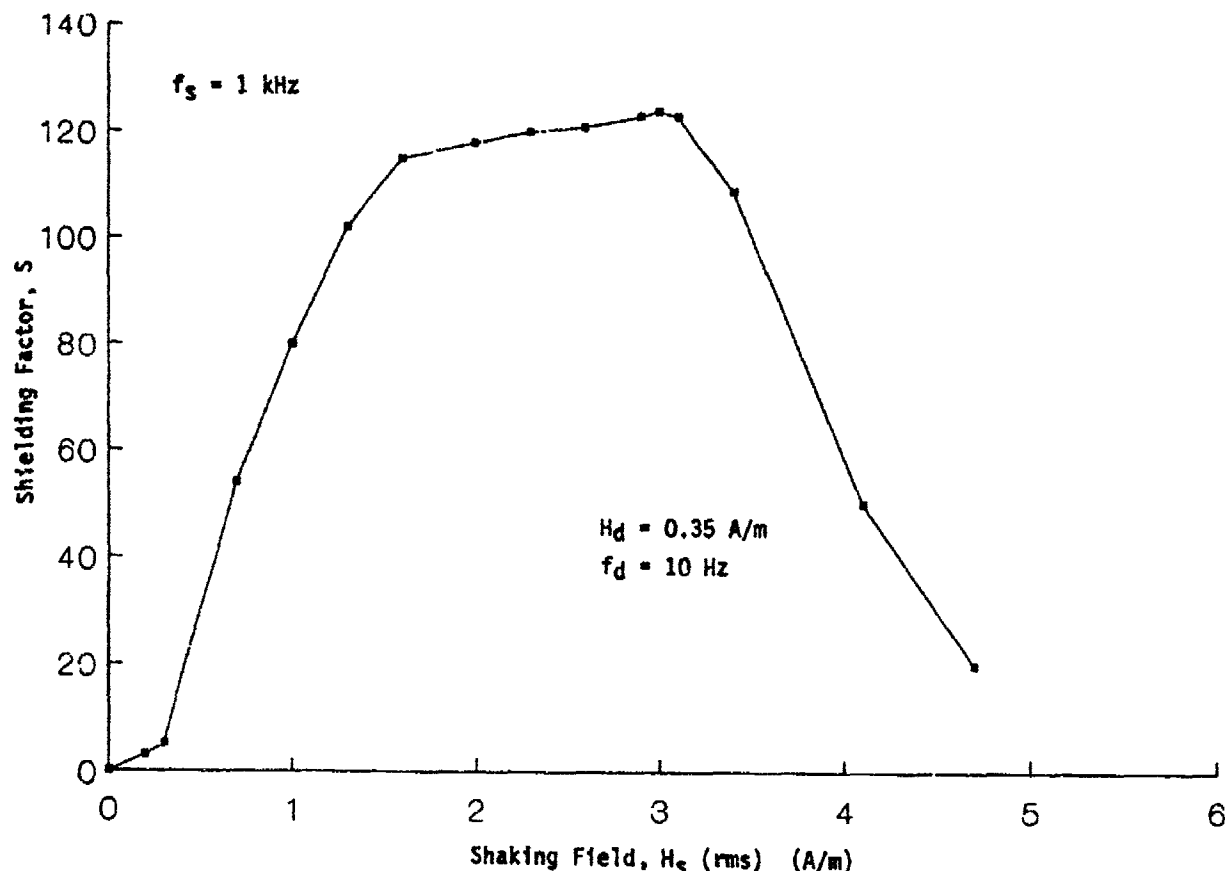
Figure 4. Shielding factor versus shielding field amplitude for fixed shaking and disturbing frequencies. Data are those of Sasada (Ref 10) for a single layer of Metglas 2705M ribbon wrapped helically on a copper pipe.

DISCUSSION

Magnetic shaking is not a widely known phenomenon. Neither Bozorth nor Chikazumi mention it in their texts, although Bozorth does discuss hysteresis curves in superposed fields. (He cautions that in spite of a common misconception, hysteresis loss cannot be reduced by superposing an oscillating field.) But there is by now no longer any doubt that shaking works. It is a cheap and effective way to improve magnetic shielding. Since coils are usually emplaced anyway to buck out dc fields and to demagnetize the shield, shaking is an easily attained improvement. A question that has not been fully addressed is the criteria for the selection of the shield material. Sasada shows that with a nonmagnetostrictive material of small coercive force and rectangular hysteresis loop, a remarkable improvement in shielding can be achieved. His work also lends support to the picture of freeing up domain walls by feeding in energy.

REFERENCES

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Ichiro Sasada is an associate professor in the Department of Electronics of Kyushu University. He now (07/88--07/89) holds a sabbatical visiting research appointment in the Department of Materials Science and Engineering, Massachusetts Institute of Technology, in Prof. Robert O'Handley's laboratory. Prof. Sasada's principal activity has been in applied magnetics and signal processing techniques (hysteresis compensation) for sensors and actuators. His publications and patents describe magnetostrictive shaft torque sensors, amorphous magnetic cores in power applications, and the effect of radial magnetic fields on tapewound cores. A current interest, along with magnetic shielding, is an algorithm for hysteresis compensation that can be used to extract the signal from a sensor with hysteresis and to control actuators with hysteresis.

THE FOURTH INTERNATIONAL CONFERENCE ON IMMUNOPHARMACOLOGY

Jeannine A. Majde

*A*t the Fourth International Conference on Immunopharmacology, an interesting trend towards attempting pharmacological manipulation of the immune system via neuroendocrine modulation surfaced in several of the symposia. Also, some exciting new observations in basic immunology were presented.

The Fourth International Conference on Immunopharmacology was held on 15-19 May 1988 in the center of such research, Osaka, Japan. About 250 registrants, mostly from Japan and Europe, attended the 8 symposia, 3 plenary lectures, and 26 poster workshops. While no major breakthroughs were reported, an interesting trend towards attempting pharmacological manipulation of the immune system via neuroendocrine modulation surfaced in several of the symposia. The following article will focus on the symposia presentations that highlighted this trend as well as some exciting new observations in basic immunology proper.

The Symposium on Neuroendocrine Interactions started with a presentation by K. Masek of Prague, Czechoslovakia, on the mechanism of action of muramyl dipeptide (MDP, a bacterial cell wall component also used as a synthetic immunomodulator) in the brain. MDP has long been known to be pyrogenic (cause fever) and to affect sleep (see the discussion of Krueger's work below). Masek has shown that subpyrogenic doses

of MDP increase rapid eye movement (REM) sleep while pyrogenic doses decrease REM and increase slow wave sleep (SWS). An interesting association between MDP and serotonin seems to be involved in that MDP alters serotonin turnover and blocks serotonin receptors; parachlorophenylalanine, a serotonin antagonist, inhibits the sleep response to MDP and increases sensitivity to pain, which is blocked by MDP.

J. Krueger of the University of Tennessee, Memphis, presented Office of Naval Research (ONR) supported work on entry of bacterially derived MDP, thought to serve as a vitamin, into the brain. Macrophages that capture and digest bacteria escaping the intestine degrade the cell walls of these organisms to leave MDP fragments, which are not degradable by mammalian enzymes due to unique sugars and D-amino acids. Krueger previously discovered that a SWS-inducing factor in mammalian brain was an MDP derivative and has developed a mass spectroscopy technique to monitor femtomole amounts of the material in brain tissue. Binding sites for MDP were found on glial cells (the "support system" of the brain) that vary in affinity and density within the regions of the brain thought to be responsible for the sleep response. MDP may regulate sleep directly or through inducing cytokines such as interleukin-1 (IL1), interferon-α (IFN-α), or tumor necrosis factor (TNF), all of which are pyrogenic and somnogenic. These cytokines, in turn, may act via prostaglandins, particularly PGD_2.

E. Smith of the University of Texas, Galveston, also presented ONR-supported work on bidirectional communication between the brain and the immune system. His classic work on adrenocorticotropin hormone (ACTH) synthesis by lymphocytes stimulated by either microbes or corticotropin releasing factor (CRF) was extended to show that glucocorticoids inhibit ACTH and CRF induction in lymphocytes as they do in the brain. He has recently shown that bacterial endotoxin and CRF induce different forms of endorphins and ACTH in lymphocytes, indicating that post-transcriptional regulation differs with different signals. He has continued to reveal that lymphocytes make pituitary hormones when properly stimulated; recently he demonstrated that chorionic gonadotropin is produced during an *in vitro* equivalent of the transplant rejection response, the mixed leukocyte reaction. The role of chorionic gonadotropin, normally associated with ovulation, in this immune response is unknown; this hormone is also synthesized by bacteria with an equally mysterious function. While the role of all of these pituitary hormones in the immune system remains obscure, ACTH has recently been shown to inhibit IFN-γ synthesis by activated T cells; IFN-γ is critical for activating macrophages to kill microorganisms and secrete cytokines. Smith has characterized ACTH receptors on immune system cells and found them to be comparable to adrenal receptors and to be widely distributed among B lymphocytes and macrophages (50 percent) and less so among T lymphocytes (25 percent).

M. Gurney of the University of Chicago described his fascinating new factor named neuroleukin. Neuroleukin is a large protein (56 kD) found in salivary gland, skeletal muscle, astrocytes, and activated T lymphocytes. In a dimeric form it functions as an enzyme, glucoisomerase; as a monomer it functions as a growth factor for sensory neurons. Neuroleukin shares an extensive homology with human immunodeficiency virus (HIV) gp120, a protein that is neurotoxic and thought to cause the neuropathology of AIDS. It is likely that blockade of the neuroleukin receptor in the brain by gp120 may cause the brain shrinkage characteristic of AIDS; TNF induction in the brain may be responsible for the characteristic vacuolar cytopathology.

A workshop presentation by A. Allison of Syntex Research featured an observation that IL1-β synthesis by macrophages is blocked by glucocorticoids; selective degradation of mRNA for IL1-β, but not IL1-α, occurs. Allison proposed that since IL1 induces CRF in hypothalamus, which then induces ACTH in pituitary, which then induces glucocorticoids in adrenal, IL1 should be considered part of the classical loop regulating glucocorticoid synthesis. Since IL1 was recently shown by others to be widely distributed in brain neurons as well as in macrophages, it will be interesting to determine the effect of glucocorticoids on brain IL1 synthesis and whether IL1 acts as a neurotransmitter in CRF-inducing neurons.

Another symposium was directed at one of the most controversial areas in cytokine research relating to the factor variously termed interleukin-6 (IL6), INF-β₂, B cell stimulating factor, and hepatocyte stimulating factor. Cloning the gene has resolved the single identity of all these substances but left the controversy regarding its interferon, or antiviral, activity. M. Revel of the

Weizmann Institute in Israel and J. Vilcek of New York University, New York, determined by different methods that the molecule is not an interferon *per se* (despite some homology with IFN-β_1) but stimulates production of classical IFN-β_1. IL6 is the current name of choice for this cytokine, and its role in host defenses is quite central. It is made by fibroblasts and macrophages, and probably many other cells, in response to bacterial endotoxin and TNF. IL1 synergizes its induction. Its primary function appears to be induction of the classical acute phase response in the liver, which leads to synthesis of C-reactive protein, serum amyloid A, α_1-protease, fibrinogen, and ceruloplasmin, among others. The acute phase response is a general protective reaction on the part of the liver that deprives microorganisms of essential nutrients such as iron, regulates blood clotting, agglutinates certain bacteria, and other nonspecific protective functions. It appears in reaction to all forms of cell injury, including anoxia. The role of all of the defined acute phase reactants is not known, and determining their functions and regulation by cytokines and neuroendocrine hormones represents one of the frontiers in immunology. It is perhaps pertinent that E. Smith (see discussion above) demonstrated that IL6 is about 100 times more potent than CRF at stimulating ACTH production, possibly explaining the adrenal activation seen in response to cell injury.

Another area of immunology that is developing with the aid of molecular biology techniques is the demonstration of functional heterogeneity in immune cell populations. F. Austen of Harvard presented elegant studies in his plenary lecture on mast cell heterogeneity regulated by the cellular environment. Mast cells residing in connective tissue develop a different response to external signals than mast cells residing in mucosa. A characteristic product of mast cells is proteoglycans that are stored in distinctively staining granules and released upon cell stimulation. Connective tissue mast cells (CM) secrete heparin and large amounts of histamine while mucosal mast cells (MM) secrete chondroitin and less histamine. They also secrete different eicosenoid products: CM make PGD$_2$ while MM make LTC$_4$. These observations provide an explanation for the role of these cells in various allergic conditions. CM grow and maintain these properties with the aid of an undefined fibroblast product; MM require T lymphocyte products and proliferate in the presence of IL3. Bone marrow mast cells plus T cell factors plus IL3 differentiate to MM, which in the presence of fibroblast factors differentiate to CM. Similar studies are in progress on cultured eosinophils to determine what environment leads to cells competent to kill parasites. Cellular environment, and its regulation of gene products, may prove to be as important as cellular receptor properties in determining responses to various challenges.

Another development in immunology is the delineation of signal transduction processes in immune system cells, featured in the final symposium. W. Farrar of NCI, Bethesda, described the response of T lymphocytes to the growth factor IL2. A new transducer protein with the phosphorylation properties of phosphokinase C, but which is Mg ion dependent rather than Ca ion dependent, is activated by IL2 and rapidly phosphorylates a 68-kD protein of unknown function but which is associated with growth signals in other immune system cells. Phosphorylation occurs by some other process than cAMP. Oncogenes c-fos

and c-myb but not c-myc are induced by IL2, as is ornithine decarboxylase; IL2 also induces heat shock or stress proteins HSP 70 and HSP 90. This system would appear to define a new route for signal transduction that bypasses the classical transducers such as phosphatidyl inositol, phosphokinase C, and cAMP but still responds to phorbol myristate. Its elucidation is likely to be applicable to other cell types. T. Ishizaka of Johns Hopkins, Baltimore, described her work on a novel G-binding protein in mast cells and basophils. F. Russo-Marie of the Institut Pasteur, Paris, France, described the debunking of lipocortin, a molecular class previously thought to regulate phospholipase A_2 and thus arachidonate metabolism and to be the target of glucocorticoids in inflammatory cells. Lipocortin turned out to be a cytoskeletal protein that nonspecifically inhibits phospholipase A_2. A new method of purifying T cells developed by N. Berry at Kobe University, Japan, has clarified some other points of confusion due to mixed cell populations and allowed the characterization of phosphokinase C species in T cells.

The reader may note that this article contains very little pharmacology, much of which was discussed at the meeting workshops. I have emphasized the basic immunology here largely because the immunopharmacology presented broke no new ground, whereas the basic immunology indicated a number of new target systems for manipulating the immune system. Currently immunopharmacology largely focuses on microbial products for stimulation and eicosenoid inhibitors for blockade of inflammation. The organizers of this conference wisely chose to open new doors for immunopharmacologists rather than to feature the descriptive, and often uninformative, studies with classical immunomodulators. Industrial support of the field is strong, at least in Japan, where 64 pharmaceutical houses were listed as sponsors of this conference. It is to be hoped that when the next international conference is held in 1991 (in Tampa, Florida), these new targets will yield new directions in what is a clinically important, if somewhat stagnant, field of research.

INTERNATIONAL MEETINGS IN THE FAR EAST
1988-1994

Compiled by Yuko Ushino

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The Australian Academy of Science, the Japan Convention Bureau, and the Science Council of Japan are the primary sources for this list. Readers are asked to notify us of any upcoming international meetings and exhibitions in the Far East which have not yet been included in this report.

	1988		
Date	Title/Attendance*	Site	Contact for Information
October 4-6	Electronics 88	Adelaide, Australia	Phillip Styles Exhibition Services 4 Lovell Court Clarence Gardens, SA 5039
October 10-14	International Symposium on Nuclear Medicine (ISNM 88)	Beijing, People's Republic of China	Secretariat: ISNM 88 The Capital Nuclear Medicine Center PUMC Hospital, CAMS Beijing
October 11-14	The 4th International Workshop on Electro-luminescence	Tottori, Japan	Dr. Hiroshi Kobayashi Department of Electronics Faculty of Engineering Tottori University Koyama, Tottori 680
October 12-15	International Conference on Hydrometallurgy	Beijing, People's Republic of China	Mr. Nie Kuolin, Director Beijing Research Institute of Uranium Ore Processing P.O. Box 234 Beijing
October 17-19	International Symposium on New Developments in Applied Superconductivity	Suita, Japan	Secretariat: Laboratory for Applied Superconductivity Department of Engineering Osaka University 2-1 Yamadaoka Suita City, Osaka 565
October 17-19	Conference on Radiation Curing Asia '88 (CRCA '88)	Tokyo, Japan	CRCA Organizing Committee c/o Y. Tabata Nuclear Engineering Research Laboratory Faculty of Engineering University of Tokyo Hongo, Bunkyo-ku, Tokyo 113

*Note: Data format was taken from the Japan International Congress Calendar published by the Japan Convention Bureau.

        No. of participating countries
F: No. of overseas participants
J: No. of Japanese participants

		1988	
Date	Title/Attendance	Site	Contact for Information
October 17-20	The 9th International Conference on Pattern Recognition	Beijing, People's Republic of China	9 ICPR Secretariat Chinese Association of Automation P.O. Box 2728 Beijing
October 18-22	Surface Engineering International Conference	Tokyo, Japan	Secretariat c/o Cotec Sankocho Building 5-17-14 Shinjuku Shinjuku-ku, Tokyo 160
October 19-21	International Sessions in JSASS 26th Aircraft Symposium	Sendai, Japan	Dr. Shigeaki Nomura Chairman of International Sessions JSASS 26th Aircraft Symposium c/o The Japan Society for Aeronautical and Space Sciences (JSASS) Kokukaikan-Bunken 1-8-2 Shinbashi Minato-ku, Tokyo 105
October 19-22	BIDEC International Bio-Fair/ Tokyo '88 Symposium 19 F120-J800	Tokyo, Japan	Secretariat of BIO FAIR TOKYO '88 Symposium c/o Japan Convention Services, Inc. Nippon Press Center Building 2-2-1 Uchisaiwai-cho Chiyoda-ku, Tokyo 100
October 24-26	The 1st International Conference New Diamond Forum 20-F150-J250	Tokyo, Japan	Secretariat: International Communications Inc. Kasho Building 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
October 24-28	The 3rd International Conference on Surface Engineering	Tokyo, Japan	Cotec Corporation Sankocho Building 5-17-14 Shinjuku Shinjuku-ku, Tokyo 160
October 25-28	International Conference on Materials and Process Characterization for VLSI (ICMP '88)	Shanghai, People's Republic of China	Zhu Ye Institute of Materials Science Fudan University Shanghai
October 25-28	Asia Electronics 88	Singapore	Interfama Exhibition 1 Marine Parade Central #10-03/06 Parkway Builders' Centre Singapore 1544
November 1-4	The 4th Asia and Oceania Congress of Nuclear Medicine	Taipei, Taiwan	Wilfredo M. Sy Department of Nuclear Medicine Brooklyn Hospital 121 Dekalb Ave. Brooklyn, NY 11201
November 2-5	International High-Performance Vehicle Conference	Shanghai, People's Republic of China	Ship Design Committee CSNAME P.O. Box 3053 Shanghai
November 5-8	The 1st International Conference on the Metallurg and Materials of Tungsten, Titanium, Rare Earths, and Antimony	Changsha, People's Republic of China	Secretariat of W-Ti-RE-Sb '88 The Nonferrous Metals Society of China 9 Xizhang Hutong, Sizhimennei Dajie Beijing
November 6-10	International Symposium and Exposition on Robots	Sydney, Australia	R.A. Jarvis GPO Box 1527 Sydney, NSW 2001

Date	Title/Attendance	Site	Contact for Information
November 8-10	The 2nd Japan-China Bilateral Conference on Molten Salt Chemistry and Technology	Yokohama, Japan	Professor Masao Takahashi Materials Science & Chemical Engineering Faculty of Engineering Yokohama National University 156 Tokiwadai Hodogaya-ku, Yokohama 156
November 8-12	The 2nd International Conference on Formulation of Semiconductor Interface (ICFSI-88)	Takarazuka, Japan	Tsunemasa Taguchi Faculty of Engineering Osaka University 2-1 Yamadaoka Fukita-shi, Osaka 565
November 11-14	International Symposium on Geothermal Energy, 1988

30-F50-J200 | Kumamoto and Beppu, Japan | Geothermal Research Society of Japan c/o Geological Survey of Japan 1-1-3 Higashi Tsukuba, Ibaraki 305 |
November 14-17	The 3rd International Topical Meeting on Nuclear Power Plant Thermal Hydraulics and Operations	Seoul, Korea	Dr. Jong Hee Cha P.O. Box 7 Daeduk-Danji Choong-Nam, Korea 300-31
November 14-17	The 9th International Acoustic Emission Symposium	Kobe, Japan	The Japanese Society for Nondestructive Inspection Hashimoto Building 3F 5-4-5 Asakusabashi Taito-ku, Tokyo 111
November 14-17	The 3rd International Topical Meeting on Nuclear Power Plant Thermal Hydraulics and Operations	Seoul, Korea	Jont H. Kim Electric Power Research Institute 3412 Hillview Ave. P.O. Box 10412 Palo Alto, CA 94303
November 14-18	1988 Annual Meeting of the International Society for Interferon Research

28-F300-J500 | Kyoto, Japan | Organizing Committee of ISIR '88 c/o Inter Group Corporation Shohaku Building 6-23 Chayamachi Kita-ku, Osaka 530 |
| November 15-19 | International Symposium on Refractories | Hangzhou, People's Republic of China | Chinese Society of Metals 46 Dongsixi Dajie Beijing |
| November 16-18 | Techno-Ocean '88 International Symposium

5-F50-J250 | Kobe, Japan | World Import Mart Co., Ltd. World Import Mart Building 3-1-3 Higashi-Ikebukuro Toshima-ku, Tokyo 170 |
| November 19-26 | The 13th International Diabetes Federation Congress

20-F80-J120 | Sydney, Australia | Professor J. R. Turtle Professor of Medicine Department of Endocrinology University of Sydney NSW 2006 |
| November 21-25 | Seminar for Asia and the Pacific on Nuclear Techniques in Prasitic and Communicable Diseases | Bombay, India | Conference Service Section, IAEA P.O. Box 100 A-1400 Vienna, Austria |
| November 22-25 | Fracture Mechanics in Engineering Practice | Melbourne, Australia | Dr. Neil Ryan Aircraft Materials Division Aeronautical Research Laboratories GPO Box 4331 Melbourne, 3001 Victoria |

Date	Title/Attendance	Site	Contact for Information
November 28- December 2	International Conference on Fifth Generation Computer Systems 1988 39-F500-J1,200	Tokyo, Japan	Institute for New Generation Computer Technology 21F Mita-Kokusai Building 1-4-28 Mita Minato-ku, Tokyo 108

Date	Title/Attendance	Site	Contact for Information
January 31- February 3	The 17th Australian Polymer Symposium	Brisbane, Australia	Dr. D.J.T. Hill Chemistry Department University of Queensland Brisbane 4067 QLD
February 1-5	International Symposium on Industrial Metal Finishing	Tamilnadu, India	Dr. S. Guruviah Central Electrochemical Research Institute Karaikudi 623006 Tamilnadu, India
February 5-6	Advances in Biomedical Polymers	Perth, Australia	The Secretary, W.A. Polymer Group Royal Australian Chemical Institute 125 Hay Street Perth, WA 6000 Australia
April 3-5	International Symposium for Electromachining 16-F100-J300	Nagoya, Japan	Institute of Industrial Science University of Tokyo 7-22-1 Roppongi Minato-ku, Tokyo 106
April 10-13	The International Symposium for Electromachining 15-F100-J300	Undecided	The Institute of Electrical Engineers of Japan Gakkai Center Building 2-4-16 Yayoi Bunkyo-ku, Tokyo 113
April 10-15	International Conference on Modernization of Steel Rolling	Beijing, People's Republic of China	ICMSR Secretariat Chinese Society of Metals 46 Dongsixi Dajie Beijing
April 11-14	International Symposium on Ship Resistance and Powering Performance (ISRP)	Shanghai, People's Republic of China	International Symposium on Ship Resistance and Powering Performance Department of Naval Architecture and Ocean Engineering Shanghai Jiao Tong University Shanghai
April 18-21	The 2nd Asian Fisheries Forum 30-F150-J150	Tokyo, Japan	Secretariat: The 2nd Asian Fisheries Forum c/o Faculty of Agriculture Tokyo University 1-1-1 Yayoi Bunkyo-ku, Tokyo 113
May 14-18	The 3rd World Conference on Neutron Radiography	Osaka, Japan	Research Reactor Institute, Kyoto University Kumatoricho, Sennan-gun, Osaka 590-04
May 29- June 2	The 2nd International Near Infrared Spectroscopy Conference	Tsukuba, Japan	Dr. Sumio Kawano National Food Research Institute Kannondai, Tsukuba 305

Date	Title/Attendance	Site	Contact for Information
July 2-7	XXVII International Conference on Coordination Chemistry	Brisbane, Australia	Professor Clifford J. Hawkins Department of Chemistry University of Queensland Saint Lucia, Brisbane, Queensland 4067
July 3-7	ICOMAT '89: The 6th International Conference for Martensitic Transformations	Sydney, Australia	ICOMAT '89 c/o N.F. Kennon Department of Metallurgy and Materials Engineering University of Wollongong P.O. Box 1144 Wollongong, NSW 2500, Australia
July 9-14	The 4th International Conference on Scanning Tunneling Microscopy/ Spectroscopy (ICSTM/STS)	Oharai, Japan	Professor Osamu Faculty of Science Tokyo Institute of Technology 2-12-1 Ohokayama Meguro-ku, Tokyo 152
July 10-14	The 4th International Symposium of Plant Biosystematics (IOPB) 30-F80-J200	Kyoto, Japan	IOPB Symposium c/o Department of Botany Faculty of Science, Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
July 17-20	The 9th International Conference on Internal Friction and Ultrasonic Attenuation in Solids (ICIFUAS 9)	Beijing, People's Republic of China	Professor T.S. Ke Laboratory of Internal Friction and Defects in Solids Institute of Solid State Physics Academia Sinica Hefei
July 24-28	The 2nd Microoptics Conference/The 8th Topical Meeting on Gradient-Index Imaging Systems (MOC/GRIN '89)	Tokyo, Japan	Mr. Yasuhiko Noguchi Secretariat: MOC/GRIN '89 Banda Building 1-35-5 Yoyogi Shibuya-ku, Tokyo 151
August 13-18	Solar Energy Congress Tokyo 1989 40-F600-J400	Tokyo, Japan	Japanese Section of International Solar Energy Society 322 San Patio 3-1-5 Takada-no-baba Shinjuku-ku, Tokyo 160
August 19-23	The 4th Asian Congress of Fluid Mechanics	Hong Kong	Professor N.W.M. Ko 4ACFM Secretariat c/o Department of Mechanical Engineering University of Hong Kong Pokfulam Road, Hong Kong
August 20-25	The 9th International Conference on Crystal Growth (ICCG) 48-F250-J550	Sendai, Japan	Secretariat: 9th International Conference on Crystal Growth c/o Inter Group Corp. 8-5-32 Akasaka Minato-ku, Tokyo 107
August 21-26	The 14th International Conference on High Energy Accelerators	Tsukuba, Japan	Mr. Kitagawa National Laboratory for High Energy Physics 1-1 Ooho Tsukuba-shi, Ibaraki 305
August 25-28	The 7th International Conference on Composite Materials (ICCM-7)	Beijing, People's Republic of China	Tu Dezheng China Society of Aeronautics and Astronautics 67 South Street Jiao Daokou, Beijing

Date	Title/Attendance	Site	Contact for Information
August 27- September 1	The 5th International Symposium on Microbial Ecology (5th ISME) 73-F600-J600	Kyoto, Japan	Organizing Committee of 5th International Symposium on Microbial Ecology c/o Inter Group Corporation 8-5-32 Akasaka Minato-ku, Tokyo 107
August 28-31	International Symposium on Computational Fluid Dynamics-- Nagoya, 1989	Nagoya, Japan	Professor Michiru Yasuhara Department of Aerospace Engineering Nagoya University Furo-cho, Chikusa-ku, Nagoya 464-01
September 4-8	The 7th International Conference on Liquid and Amorphous 30-F120-J280	Kyoto, Japan	Department of Physics, Faculty of Science Kyoto University Oiwake-cho, Kita-Shirakawa Sakyo-ku, Kyoto 606
September 4-8	ISES Solar World Congress 1989 Kobe 65-F400-J400	Kobe, Japan	Secretariat: ISES Solar World Congress 1989 c/o International Communications, Inc. Kasho Building 2-14-9 Nihonbashi Chuo-ku, Tokyo 103
September 5-7	International Conference on Zinc and Zinc Alloy Coated Steel Sheet 20-F50-J150	Tokyo, Japan	Secretariat of GALVATECH '89 Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
September 8-10	1989 International Symposium on Electromagnetic Compatibility 26-F170-J400	Nagoya, Japan	Secretariat: International Symposium on Electromagnetic Compatibility c/o Department of Information and Computer Sciences Toyohashi University of Technology 1-1 Tenpaku-cho, Aza-Hibarigaoka Toyohashi, Aichi 440
September 12-14	Thermtech Asia 89	Hong Kong	International Symposia and Exhibitions Ltd. Queensway House 2 Queensway Redhill, Surrey RH1 1QS, UK
September 17-22	The 40th Meeting of the International Electrochemical Society	Kyoto, Japan	Professor Yoshizawa, 40th ISE Meeting Secretariat Kyoto International Conference Hall Taraike, Sakyo-ku, Kyoto 606
September 17-22	International Conference on the Science and Technology of Defect Control in Semiconductors	Yokohama, Japan	IC-STDCS c/o Lab. Physics of Crystal Defects Institute for Materials Research Tohoku University 2-1-1 Katahira Sendai 980
September 24-28	The 6th International Symposium on Passivity - Passivation of Metals and Semiconductors	Sapporo, Japan	Dr. Norio Satoh Faculty of Engineering Hokkaido University Nishi 8-chome, Kita 13-jo Sapporo-shi 060
September 25-28	The 5th International Conference on Numerical Ship Hydrodynamics N.A.-F-J200	Hiroshima, Japan	Ms. T. Kodera c/o Professor K. Mori Department of Naval Architecture and Ocean Engineering Faculty of Engineering Hiroshima University Saiji-cho, Higashi-Hiroshima 724

Date	Title/Attendance	Site	Contact for Information
October 2-4	Today's Technology for the Mining and Metallurgical Industries	Kyoto, Japan	MMIJ/IMM Joint Symposium Office Mining and Metallurgical Institute of Japan Nogizaka Building 9-6-41 Akasaka Minato-ku, Tokyo 107
October 3-5	The 10th Meeting of World Society for Stereotactic and Functional Neurosurgery 20-F200-J300	Maebashi, Japan	Department of Neurosurgery Gunma University, School of Medicine 3-39 Showa-machi Maebashi 371
October 26-28	ACEANCUPS Polymer Symposium 10-F30-J30	Osaka, Japan	Institute of Scientific and Industrial Research, Osaka University 8-1 Mihogaoka Ibaraki-City, Osaka 567
October (tentative)	Specialty Electric Conference	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600
November 20-23	International Conference Evaluation of Materials Performance in Severe Environments-Evaluation and Development of Materials in Civil and Marine Uses 20-F80-J120	Kobe, Japan	International Conference Secretariat Conference and Editorial Department Iron and Steel Institute of Japan 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
November 20- December 1	The 1st International Symposium and Exhibition of SAMPE JAPAN CHAPTER	Makuhari, Japan	SAMPE P.O. Box 2459 Covina, CA 91722
December 11-15	The 10th Australasian Fluid Mechanics Conference	Melbourne, Australia	10AFMC c/o Professor A.E. Perry Department of Mechanical Engineering The University of Melbourne Parkville, Victoria 3052

Date	Title/Attendance	Site	Contact for Information
January 22-26	International Conference on Recrystallization in Metallic Materials	Wollongong, Australia	Metallurgical Society of AIME Conference Department 420 Commonwealth Drive Warrendale, PA 15086
May 19-26	The 27th International Navigation Congress 62-F500-J500	Osaka, Japan	Japan Organizing Committee for 27th International Navigation Congress of PIANC c/o Port and Harbor Bureau City of Osaka 2-8-24 Chikko Minato-ku, Osaka 552
July 15-21	The 10th International Congress of Nephrology 10-F1,000-J4,000	Tokyo, Japan	Japanese Society of Nephrology c/o 2nd Department of Internal Medicine School of Medicine, Nippon University 30-1 Oyaguchi-kamicho Itabashi-ku, Tokyo 173

1990

Date	Title/Attendance	Site	Contact for Information
August 21-29	International Congress of Mathematicians 1990 84-F1,500-J1,500	Kyoto, Japan	ICM 90 Secretariat c/o International Relations Office Research Institute for Mathematical Sciences Kyoto University Kitashirakawa Oiwake-cho Sakyo-ku, Kyoto 606
August 23-30	V International Congress of Ecology 62-F900-J1,000	Yokohama, Japan	Secretary General's Office for INTECOL 1990 c/o Institute of Environmental Science and Technology Yokohama National University 156 Tokiwadai Hodogaya-ku, Yokohama 240
September 16-22	IUMS Congress: Bacteriology and Mycology - Osaka, Japan - 1990 71-F2,000-J600	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda Kita-ku, Osaka 530
September (tentative)	The 15th International Congress on Microbiology 57-F2,500-J2,500	Osaka, Japan	Preliminary Committee of International Congress of Microbiology c/o JTB Creative Inc. Daiko Building 3-2-14 Umeda Kita-ku, Osaka 530
1990 (tentative)	The 6th International Conference on the Science & Technology of Iron and Steel 50-F300-J500	Japan (undecided)	International Conference Secretariat and Editorial Department Iron and Steel Institute of Japan 3F, Keidanren Kaikan, 1-9-4 Otemachi Chiyoda-ku, Tokyo 100
1990 (tentative)	Chemeca 1990 Applied Thermodynamics	New Zealand	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

1991

Date	Title/Attendance	Site	Contact for Information
February 10-15	POLYMER '91: International Symposium on Polymer Materials	Melbourne, Australia	Dr. G.B. Guise P.O. Box 224 Belmont, VIC 3216, Australia
August (tentative)	International Congress on Medical Physics 45-F600-J900	Kyoto, Japan	National Institute of Radiological Science 4-9-1 Anagawa Chiba 260
August (tentative)	The 16th International Conference on Medical and Biological Engineering (ICMBE)	Kyoto, Japan (tentative)	Japan Society of Medical Electronics and Biological Engineering 2-4-16 Yoyogi Bunkyo-ku, Tokyo 113

1992

Date	Title/Attendance	Site	Contact for Information
Autumn	XIVth International Switching Symposium (ISS '92)	(to be decided)	Institute of Electronics, Information and Communication Engineers (IEICE) Kikai Shinko Kaikan 3-5-8 Shiba-koen Minato-ku, Tokyo 105

		1993	
Date	Title/Attendance	Site	Contact for Information
1993 (tentative)	International Federation of Automatic Control Congress	Sydney, Australia	Conference Manager The Institution of Engineers, Australia 11 National Circuit Barton, ACT 2600

		1994	
Date	Title/Attendance	Site	Contact for Information
Tentative	XXX International Conference on Coordination Chemistry	Kyoto, Japan	Professor Hitoshi Ohtaki Department of Electronic Chemistry Tokyo Insitute of Technology at Nagatsuta 4259 Nagatsuta-cho Midori-ku, Yokohama 227